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Spectrum analyzer based phase measurement for EMI scanning applications

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SPECTRUM ANALYZER BASED PHASE MEASUREMENT FOR EMI SCANNING APPLICATIONS

by

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ABSTRACT

Often Electromagnetic Interference (EMI) scanning applications require phase and magnitude information for the creation of equivalent radiation models and for far-field predictions. Magnitude information can be obtained using a spectrum analyzer (SA), which is relatively inexpensive compared to phase resolving instruments such as oscilloscopes (scope) and vector network analyzers (VNA). The study focusses on the development of a near-field scanning method using a SA to measure the phase of the device under test (DUT) signals.

The first part deals with the development of the method in software simulation tools and testing it under standard test conditions. The second part deals with the assembly of the measurement components – phase shifting cables, switches, attenuators and combiners. The measurement method is demonstrated by measuring the phase of the known signal. In the third part the measurement method is tested on a DUT having near field radiating sources. The measurements are performed and compared to the existing methods. This study introduces and optimizes SA based phase measurements and compares the results to oscilloscope and VNA based methods for sine waves and real EMI signals.

ACKNOWLEDGMENTS

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1. INTRODUCTION

1.1. PROJECT MOTIVATION AND OBJECTIVE

Often Electromagnetic Interference (EMI) scanning applications require phase and magnitude information for the creation of equivalent radiation models and for far-field predictions. Among these applications, near-field scanning benefits strongly as source reconstruction or the application of Huygens surfaces [1] becomes possible if phase-resolved field data is provided. Magnitude information can be obtained using a spectrum analyzer (SA), which is relatively inexpensive compared to phase resolving instruments such as oscilloscopes and vector network analyzers (VNA).

Methods for performing phase measurements using a VNA or a scope have been reported in literature. The measurement method reported in [2] makes use of a VNA to measure the field in frequency domain. However, usually the VNA measures the phase with respect to internal RF source of the instrument for S-parameter measurement. In order to measure the phase the VNA is used in tuned receiver mode. In this mode the internal source is off and the phase is measured with respect to an external source. The drawback of this method is poor image and spurious rejection of many VNAs in tuned receiver mode which leads to difficulties if there are other signals present in the spectrum other than the frequency of interest. The method used in [3] measures the field in time domain using an oscilloscope, converts the data to frequency domain using fast Fourier transform (FFT), and finally extracts the phase information by subtracting the measurement phase from the phase of a reference probe. The drawback of this method is the cost and lab availability of oscilloscopes for higher frequencies. Each of the existing methods have their benefits and their shortcomings.

Near field scanning involves the measurement of a main signal (from DUT) and a reference signal. The two signals are measured using near field scanning H-field and E-field probes [4], [5]. Based on the near field emission sources on a DUT, the appropriate H-field or E-field probe is selected for the measurement. The reference probe is fixed at the location around the DUT and the main signal probe scans the DUT at a specific height above the DUT.

The SA offers various types of detectors such as quasi-peak or peak detectors which are necessary for near field scan measurements for EMI applications. The instrument can resolve magnitude relative to its own signal source, but cannot perform phase measurement. In this thesis a measurement method to measure phase using SA is developed. In [6-7], a method is described that determines the phase from multiple SA measurements. In this method, a 0° hybrid coupler sums the main signal probe and the reference probe signals. To retrieve the phase, at least three sweeps are required. Each sweep uses a different configuration for the sum of the signals. However, the method fails to obtain useful phase information if the magnitude difference between the reference probe and the field probe signals is large. Also this method has been described only for single frequency measurement.

If both phase and magnitude of field data are desired, additional devices/ components are needed to calculate phase from magnitude based spectrum analyzer measurements. The proposed SA analyzer method [8] is improved and is capable of broadband measurement which was one of the shortcomings of the hybrid based phase measurement using SA mentioned in [6-7]. The SA based measurement technique is improved in its computation time, the measurement setup is automated and needs very less user intervention during the measurement. The setup makes use of a switch to use different phase shift cable lengths and make multiple measurements to obtain the correct phase based on magnitude only measurement measured at the SA. In this thesis the current state-of the-art methods and their performance for different signal sources are reported and discussed.

1.2. METHOD DEVELOPMENT APPROACH

The research approach is divided into three main parts. The first part deals with the development of the method in software simulation tools and testing it under standard test conditions.

The second part deals involves building of measurement setups. With each measurement setup the measurement challenges were identified an improved to obtain a final Spectrum Analyzer (SA) based measurement method. Broadband frequency measurement capability, time required per scan point, time delay between the communicating instruments, dynamic range of the measurement, cost of the extra components, image frequency rejection capability were the factors to be considered while developing the SA based method. A hybrid method with the assembly of the measurement components – phase shifting cables, switches, attenuators and combiners was developed. The measurement method is demonstrated by measuring the phase of the known signal.

In the third part the final automated measurement method is tested on a real DUT measurement case having near field radiating sources. The measurements are performed and compared to the existing methods. This thesis introduces and optimizes SA based phase measurements and compares the results to oscilloscope and VNA based methods for sine waves and real EMI signals.

A market available Spectrum analyzer instrument is shown in Figure 1.1. In this work R&S Spectrum analyzer [13] was used.

Figure 1.1. Spectrum Analyzer Instrument.

2. PHASE MEASUREMENT CONCEPT

2.1. PHASE DETECTION CONCEPT USING SPECTRUM ANALYZER

The objective was to first test the phase measurement method in simulation software tool Agilent ADS. This simulation model was implemented to understand the phase detection concept and then make improvements to the existing method reported in literature [6-7]. The main idea of the existing method in literature is shown in the form of electrical schematic in Figure 2.1.

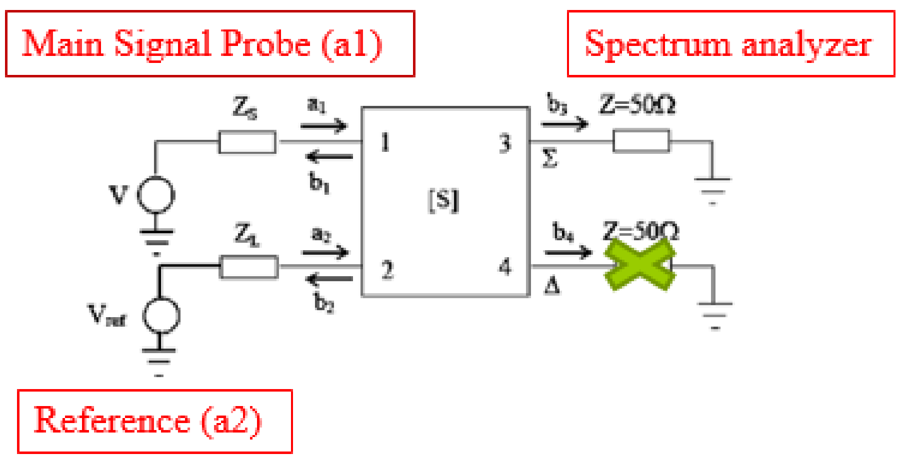

Figure 2.1. Electrical schematic of the phase measurement method.

The main signal probe signal represents the Device under test (DUT) signal (a1). The Reference (a2) is the again a signal from the DUT, but it is always kept fixed to a constant location during the scan. The box in the center [S] represents the hybrid coupler which is used for the summation measurement. The summation term is measured by the spectrum analyzer instrument. The difference term is terminated with 50 Ω. The electrical schematic depicts the concept used for the phase measurement method.

A model was built in simulation software to test the phase detection methodology. The method needs sequential steps to record the signal powers b_3, a_1, a_2 and b_3'. The individual steps are shown in the following Figure 2.2, Figure 2.3, Figure 2.4 and Figure 2.5. The terms represent the following:

- b_3 – Summation of the main signal a_1 and the reference signal a_2
- b_3' – Summation of the main signal a_1 and the reference signal a_2 when a phase shifter for example a coax cable is added in the between the main signal and the reference signal.
- a_1 – The main signal a_1
- a_2 – The reference signal a_2

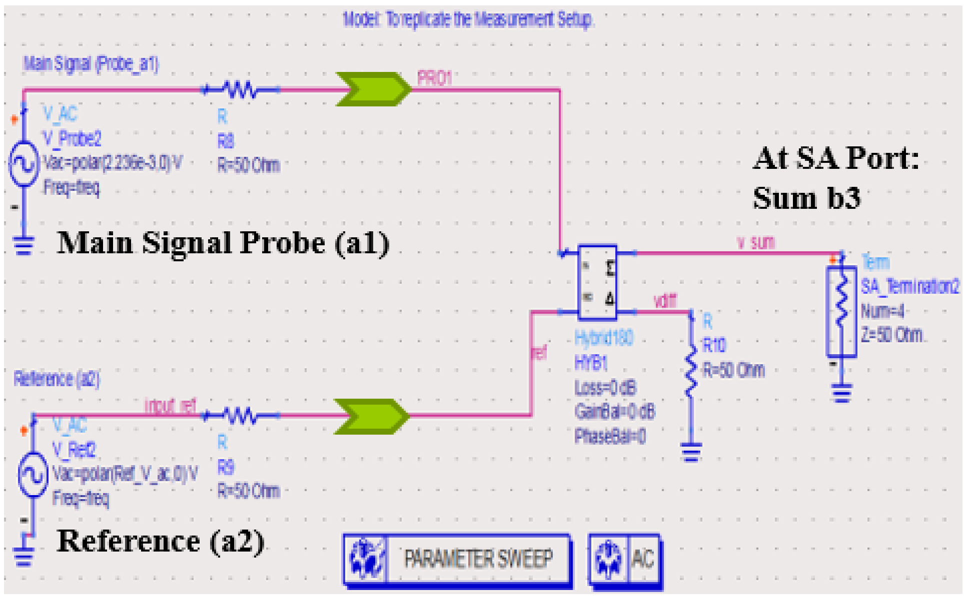

Figure 2.2. Record the summation term b_3.

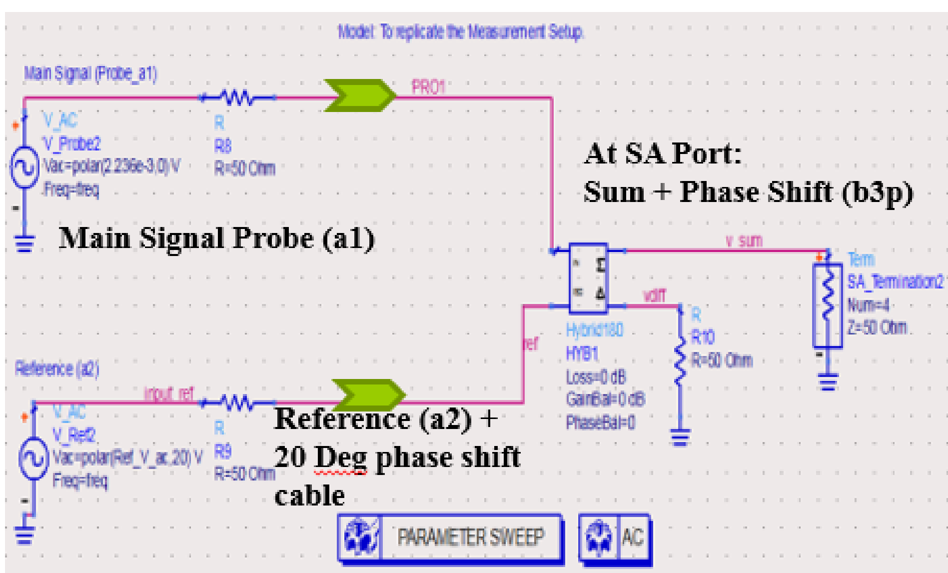

Figure 2.3. Record the phase shifted summation term b_3'.

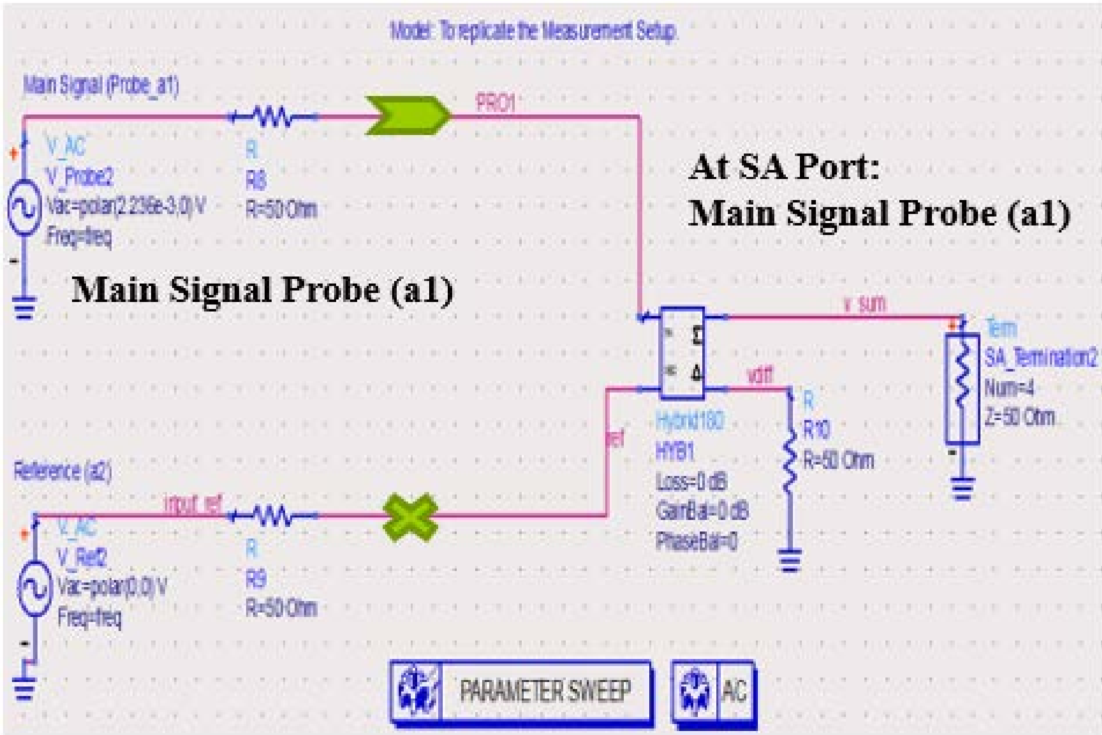

Figure 2.4. Record the main signal probe a_1.

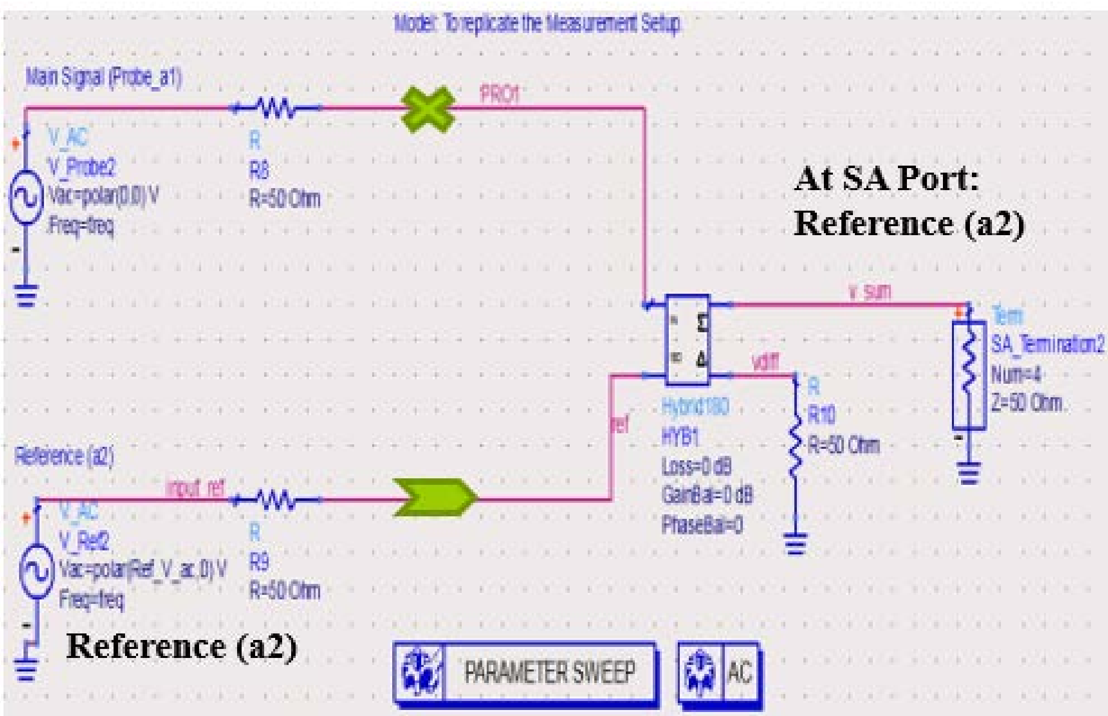

Figure 2.5. Record the reference a_2.

Using the s-parameters of the setup and mathematical treatment [6] of the four measured power values the phase information between the main signal probe and reference can be calculated.

2.2. REVISED PHASE DETECTION MODEL

The initial investigation revealed that the method cannot detect phase information if the magnitude difference between the reference probe and the main field probe signals is large. To overcome this limitation the use of various external components like the phase shifter, attenuator and amplifiers were investigated in the simulation model. Usually the reference signal is chosen to be at the strongest part of the DUT near field radiation. Hence the variable attenuator and the phase shifter components were only added on the reference path in the simulation model. The block diagram and the ADS implementation of the revised method is shown in Figure 2.6 and Figure 2.7 respectively.

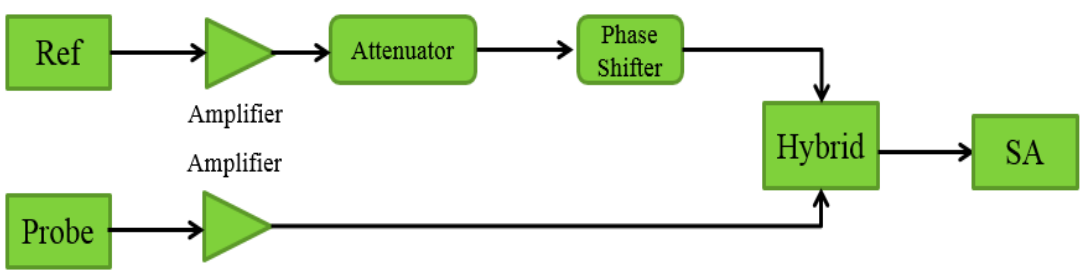

Figure 2.6. Block diagram of the revised phase measurement method.

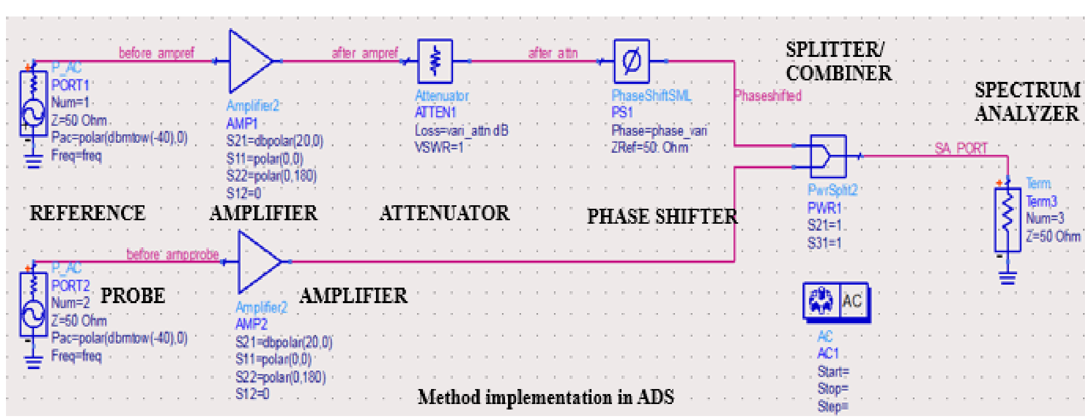

Figure 2.7. Implementation in the ADS simulation software.

The main signal and the probe were kept at equal power levels (- 40 dBm) and the effect of summation of the two signals was investigated when the phase shifter introduced phase shifts from 0° to 360° at a step size of 10°. The ADS simulation result is shown in Figure 2.8.

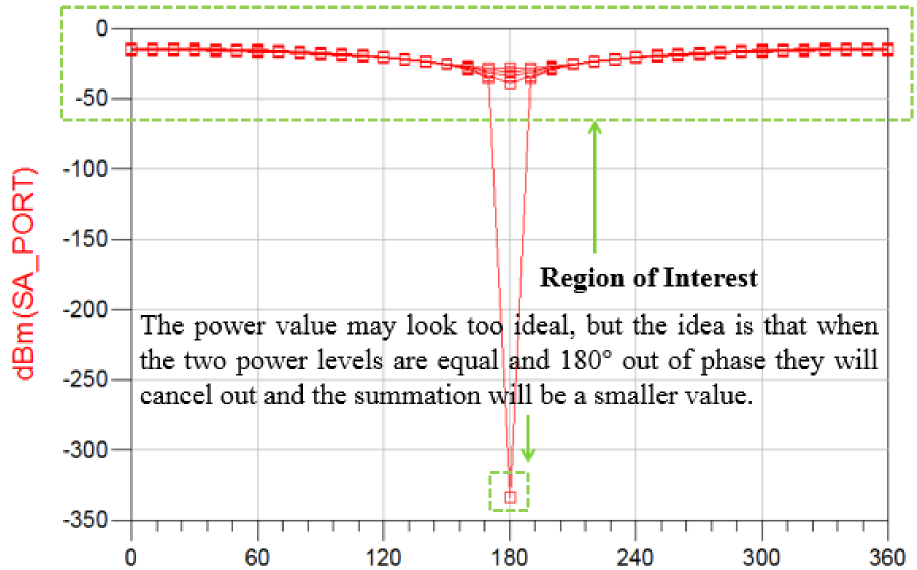

Figure 2.8. Plot of the summation power b_3 when the two input signals are phase shifted from 0° to 360° at step sizes of 10°.

The Figure 2.8 shows that for a given strength of the main signal and reference signal, when the two are added out of phase (180°) the summations leads to a lower signal power. The power value after cancellation is not important in this represent an ideal case when we have introduced no losses and this does not consider the measurement noise floor of an instrument.

Now in order to determine an acceptable difference in power levels of the two signals sources the main probe and the reference, a set of test cases were simulated to see the difference in the minimum and the maximum power recorded for one complete 0° to 360° phase shift. The goal was to determine how much of variation or difference can be allowed between the two input signals. This test case simulation helps to determine the allowable step size of the tunable attenuator placed on the reference path of this revised phase measurement model. Figure 2.9 to Figure 2.11

shows that difference between the maximum and the minimum summation power difference is 1.74 dB, 3.51 dB and 7.32 dB respectively.

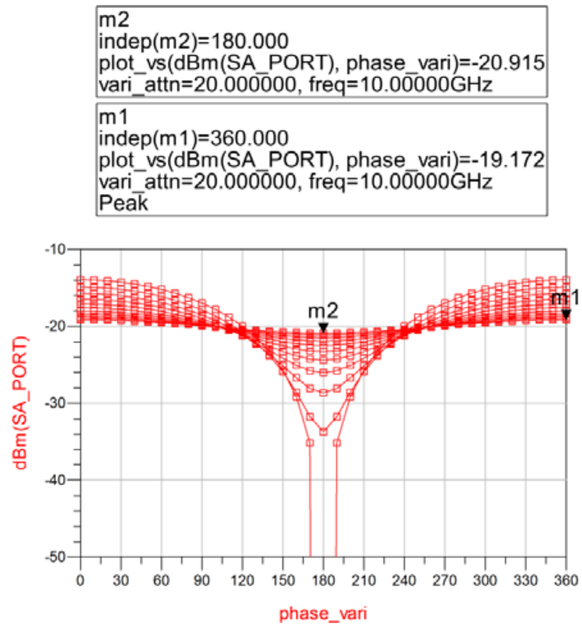

Figure 2.9. Main probe and the reference are separated by 20 dB. The effect of phase shift on minimum and maximum summation power is plotted as a function of phase shift.

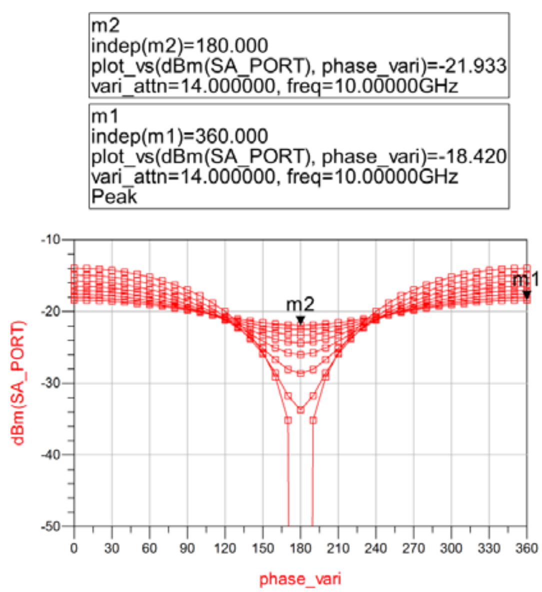

Figure 2.10. Main probe and the reference are separated by 14 dB. The effect of phase shift on minimum and maximum summation power is plotted as a function of phase shift.

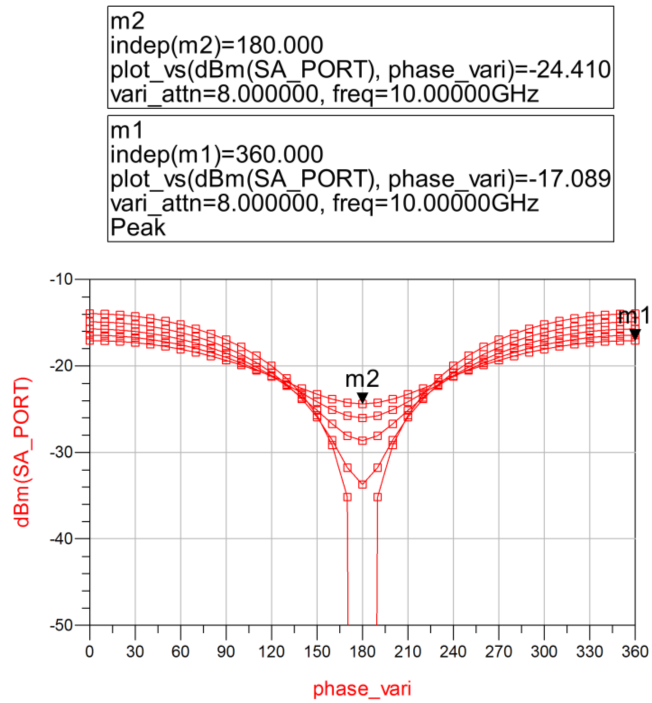

Figure 2.11. Main probe and the reference are separated by 8 dB. The effect of phase shift on minimum and maximum summation power is plotted as a function of phase shift.

The Figure 2.8 shows that when the two input signals main probe and the reference probe are equal in power the difference between the maximum and the minimum summations powers is more than 40 dB. The above simulation test cases suggests that in the measurement setup we can investigate the effect of attenuation steps sizes in the range of 8 dB. Using this as reference step size the impact of summation of the two signals will be investigated in measurement.

3. PHASE MEASUREMENT SETUPS

The measurement setup as tested in simulation is first investigated. Based on the measurement results and the measurement challenges the test setups were constantly improved to achieve a robust measurement setup for the Spectrum Analyzer based phase measurement technique.

3.1. BRUTE FORCE METHOD IMPLEMENTATION

Figure 3.1 shows the various electronic components used for the setup implementation:

- Source circuit
- Reference path
- Main probe signal path

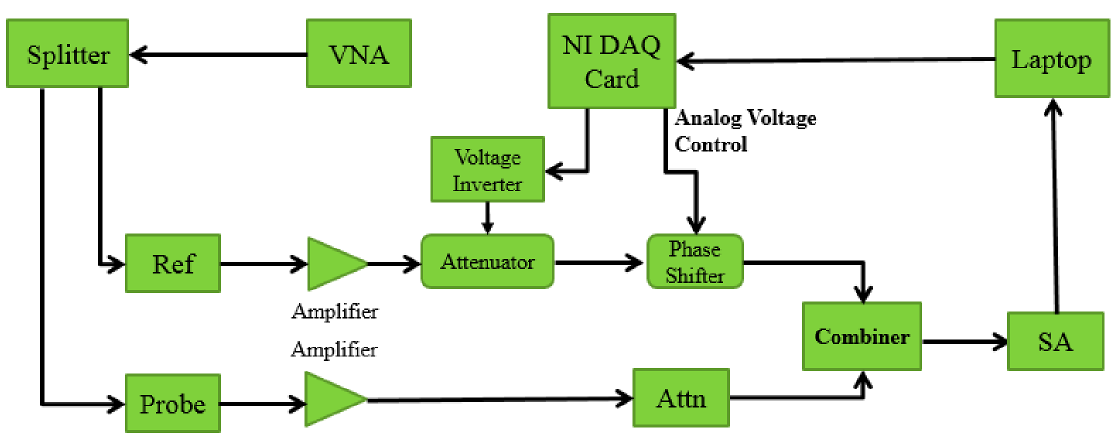

Figure 3.1. Brute force method block diagram.

Brute force method is a single frequency implementation method. It determines the phase information using the phase shift added by the phase shifter to introduce a null in the measured power at the SA. The VNA and splitter on the left side of the block diagram represent the source circuit. A known signal is generated from the VNA and then later split into reference signal and main probe signal using the splitter. This creates two signals for the measurement. The phase difference between the two paths is measured using a Spectrum Analyzer.

The phase shifter component adds different values of phase in degrees into the reference path. This introduces a phase shift in the reference signal. When the reference signal and the probe path signal get added at the combiner stage, the summation signal is measured at the Spectrum Analyzer. The attenuator in reference path to introduce attenuation against the main signal probe. This is desired in a case where the reference signal is stronger than the main probe signal, then we introduce attenuation to make the reference and the main probe signals to have almost equal power levels at the combiner stage. Figure 3.2 shows the brute force measurement setup.

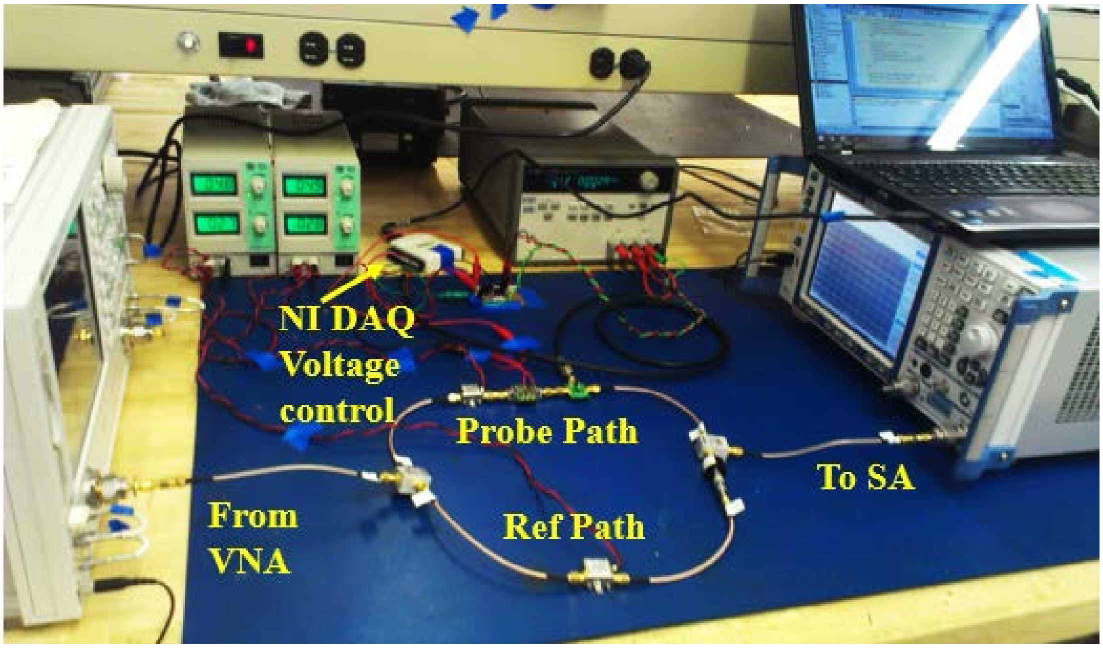

Figure 3.2. Brute force measurement setup.

The setup is verified by measuring the power levels after each component as shown in Figure 3.3. The cable loss is measured to account for the loss introduced due to cables. The VNA power is set at -20 dBm and the signal frequency of 7 GHz is chosen for the measurement. The measurement sequence is as follows:

1) Apply the Phase shifter from 0° to 360° at 1 KHz sine wave modulation.

2) Tune the Attenuator so, that we find the lowest possible null.

3) Fix that attenuation value.

4) Remove the 1 KHz modulation and just vary phase shifter within 0° to 360°.

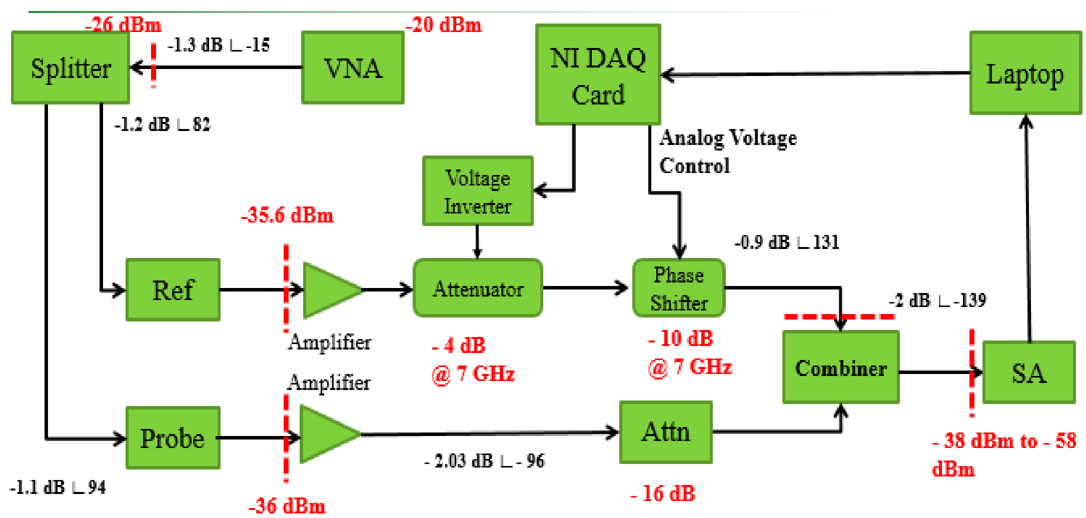

Figure 3.3. Power at each stage of the setup. Performed to verify the measurement setup and check if all the stages are functioning.

The SA is set into zero span mode. Since this is a single frequency implementation, the center frequency is set at 7 GHz. The measurement data for different attenuation and phase shifts are shown in Figure 3.4.

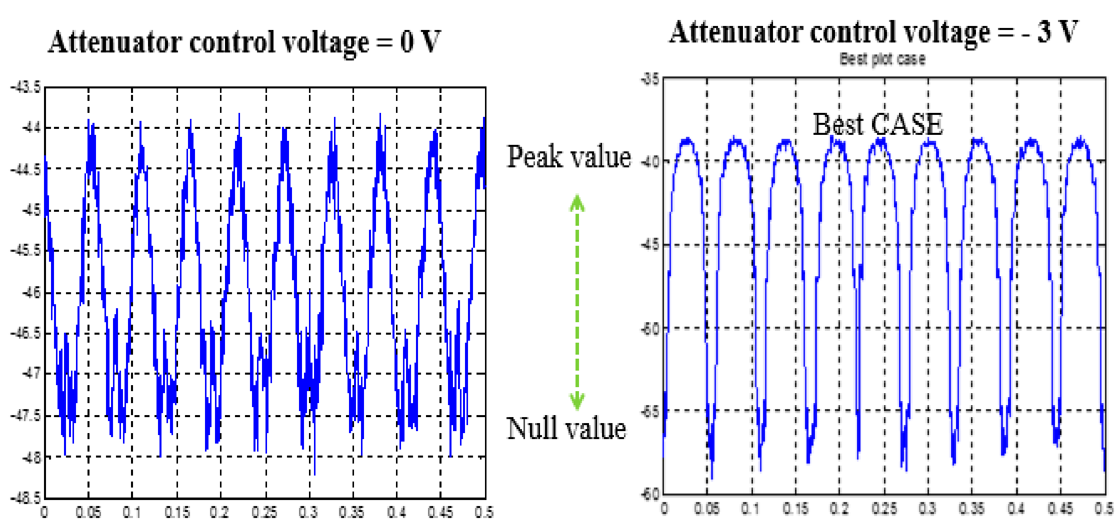

Figure 3.4. The measurement plots are shown only for the 0 V and the -3 V case. At a control voltage of the -3 V on the attenuator, the best case null is observed on the Spectrum Analyzer.

The observations from the above plots for the Single frequency method are as follows:

- The plot show the effect of different attenuation values introduced by the voltage controlled attenuator.
- The plot also shows the influence of continuous phase shift (0° to 360°) added by the phase shifter.
- This a zero span plot of the SA measurement using Brute force measurement setup.
- When the two signals have nearly equal power levels, the difference between the min and max power level is higher, as shown by the – 3 V attenuation plot in Figure 3.4.

3.2. SINGLE SWEEP METHOD IMPLEMENTATION

The brute force method relies on discrete values of control voltage fed to the voltage controlled phase shifter and voltage controlled attenuator. To automate the measurement process for the single frequency based Brute force method, we introduce continuous ramp and sine wave stimulus to the attenuator and the phase shifter. A function generator is used to generate the ramp and the sine wave control voltage. The function generator output waveforms are shown in Figure 3.5.

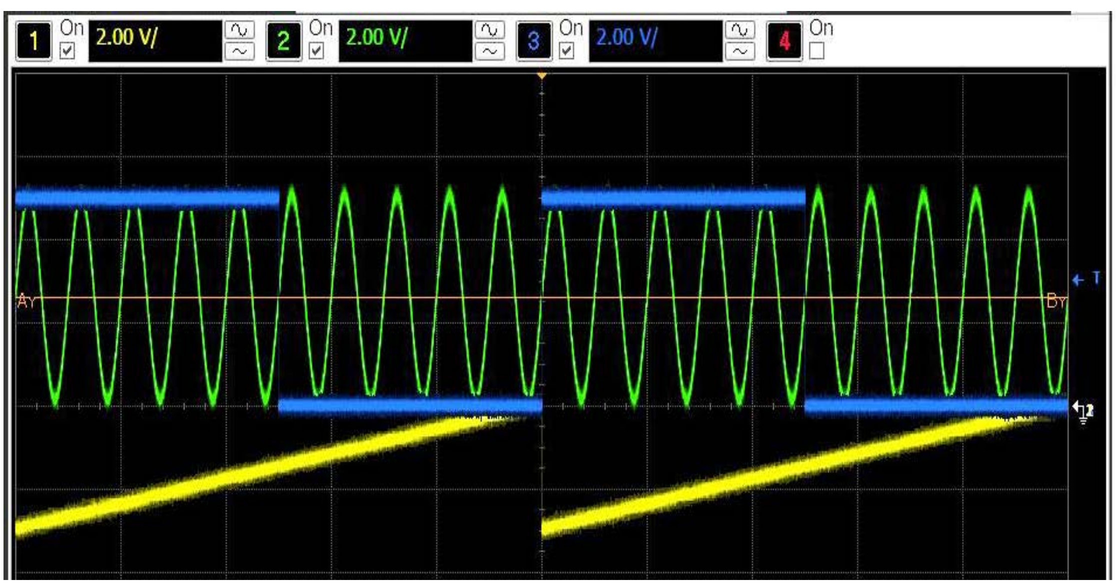

Figure 3.5. Function generator outputs for the single sweep method.

The Square wave is the trigger out signal to initiate a single sweep on the SA. The trigger out signal informs the SA to start its single sweep measurement. Ramp signal of 1 Hz is fed to the attenuator. The voltage range is from 0 V to -3 V. Sine wave of 10 Hz is fed to the Phase Shifter. The voltage range is from 0 V to 5 V. The Single sweep method block diagram is shown in Figure 3.6.

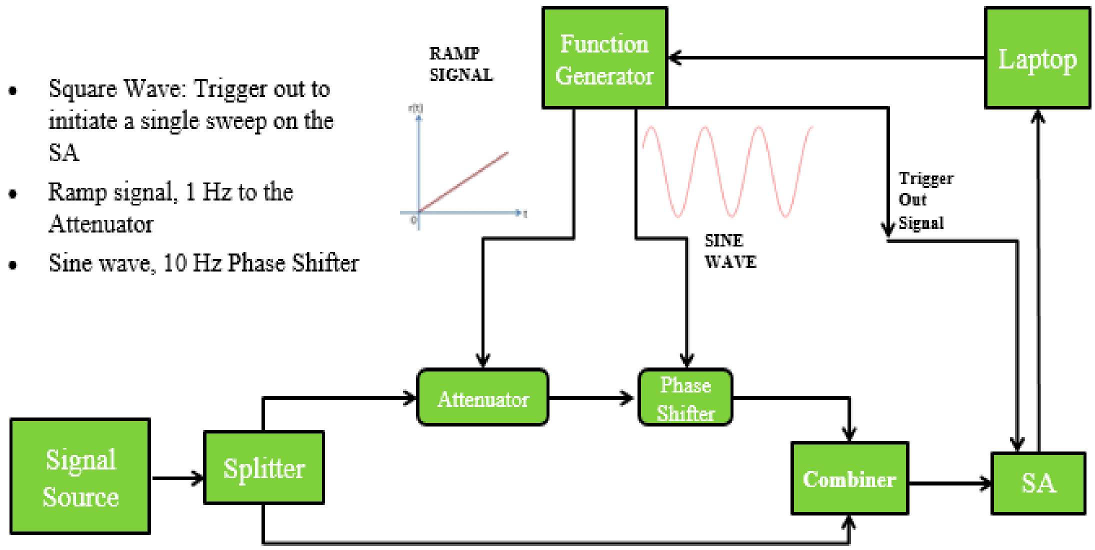

Figure 3.6. Single sweep method block diagram.

The single sweep method implementation helps to automate the control voltages applied to the phase shifter and the attenuator. Rather than discrete voltage values, now using a slow ramp signal and a faster sine wave, all the attenuation values and phase shifter values are covered faster than using the discrete voltage values in brute force implementation. The benefit of this method is the measurement time as compared to the brute force method.

3.3. HYBRID METHOD

Based on the understanding of the effect of phase shifters, attenuators and the hybrid based phase measurement in [6-7], the hybrid method is developed. The hybrid method block diagram is shown in Figure 3.7. Comb generator acts as a broad band frequency source. The function generator provides the required input signal to the comb generator to generate the necessary output signal in the frequency range from 200 MHz to 12 GHz.

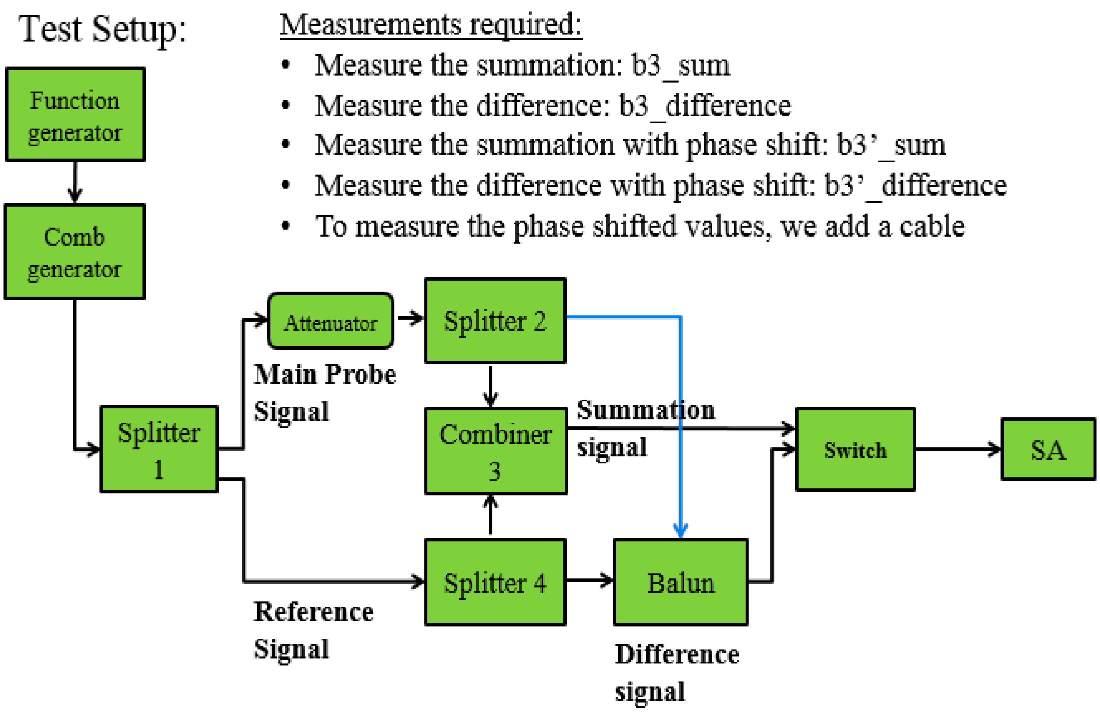

Figure 3.7. Hybrid method block diagram.

Balun adds the two signals out of phase, to give the difference signal. Power splitter/combiner to add the signals in phase. Here the two signals are the main probe and the reference signal which are added in phase by the combiner and out of phase by the balun. The hybrid method setup is shown in Figure 3.8.

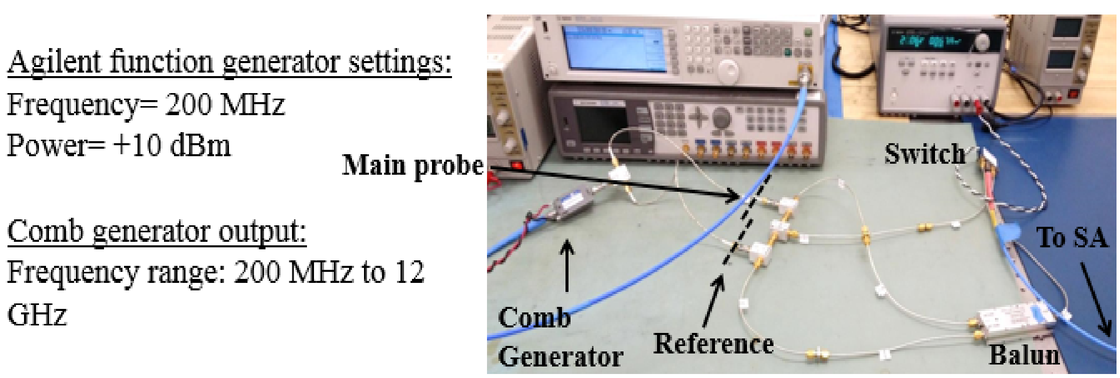

Figure 3.8. Hybrid method measurement setup.

The hybrid method requires four measurements be performed to obtain the phase information. A sum, difference and phase shifted sum and a phase shifted difference measurement. The drawback of implementing this method is that the system of components together increase the cost of the method. The balun adds the main probe and the reference signals out of phase, is quite expensive as an external component in the measurement system.

4. OPTIMIZED PHASE MEASUREMENT SETUP

This measurement setup is the final optimized setup called as the modified hybrid coupler method. This was optimized based on the knowledge from the previous setups. In order to offset the high cost of balun, the hybrid method is modified to the following setup shown in Figure 4.1.

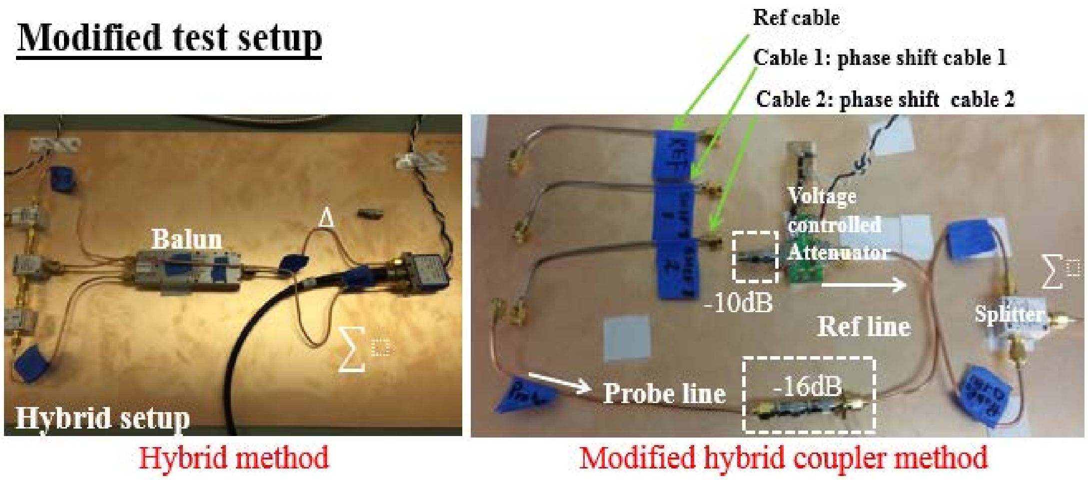

Figure 4.1. Hybrid and modified hybrid coupler method setup.

In the modified hybrid coupler setup, the balun is replaced by additional 2 phase shift cables. The measurements now needed are:

- Measure the summation with phase shift cable_ref: bsum
- Measure the summation with phase shift cable_1: bsum_c1
- Measure the summation with phase shift cable_2: bsum_c2

Now only three measurements are required, because the expensive balun was replaced by three phase shift cables. Similarly to the earlier implementations the phase shifters work is now done by three different length coax cables. The voltage controlled attenuator is introduced in the setup for varying the attenuation on the reference path.

In order to compute the phase difference at the DUT, the measurement system loss and phase needs to be corrected from the measurement results obtained at the spectrum analyzer. The entire three port measurement system is characterized by the measuring its s-parameters, as shown in Figure 4.2.

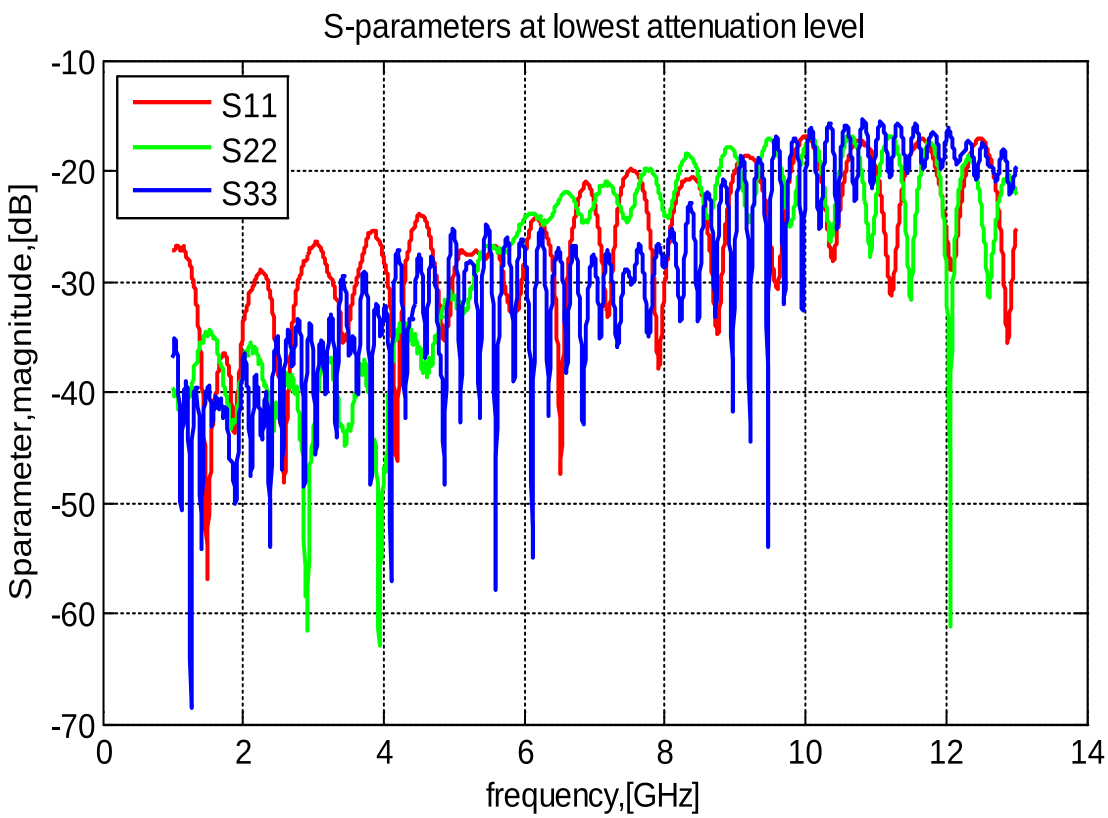

Figure 4.2. S-parameters of the modified hybrid coupler method setup. The voltage controlled attenuator in the reference path is kept at its lowest attenuation setting.

Reflections of hybrid system at lowest attenuation level are shown. At the lowest attenuation level, we expect this to be the worst-case reflections in the measurement system. The reflection parameters S_{11}, S_{22} and S_{33} should be as low as possible. A value less than 15 dB reflection can be considered to be acceptable reflections in the measurement setup.

The hybrid method used only transmission s-parameters of the system like the parameters S_{21} and S_{31} in the post-processing algorithm of this method. It is assumed in the formulation that the reflections in the system can be neglected. In order for this assumption to be valid and have accurate results additional attenuators are added in the measurement system to reduce the reflections in the setup. The attenuators are also added after combiners to reduce any reflections seen due to the combiner in the measurement system. Thus by reducing the reflection losses, most of the signal is transmitted in the system.

4.1. ALGORITHM FOR PHASE DETECTION

The method needs the reference power (magnitude of the signal) to be measured at the reference probe input. Similarly the probe power at the input of the main probe signal port in the measurement setup. These two powers are the starting point for the method algorithm shown in Figure 4.3.

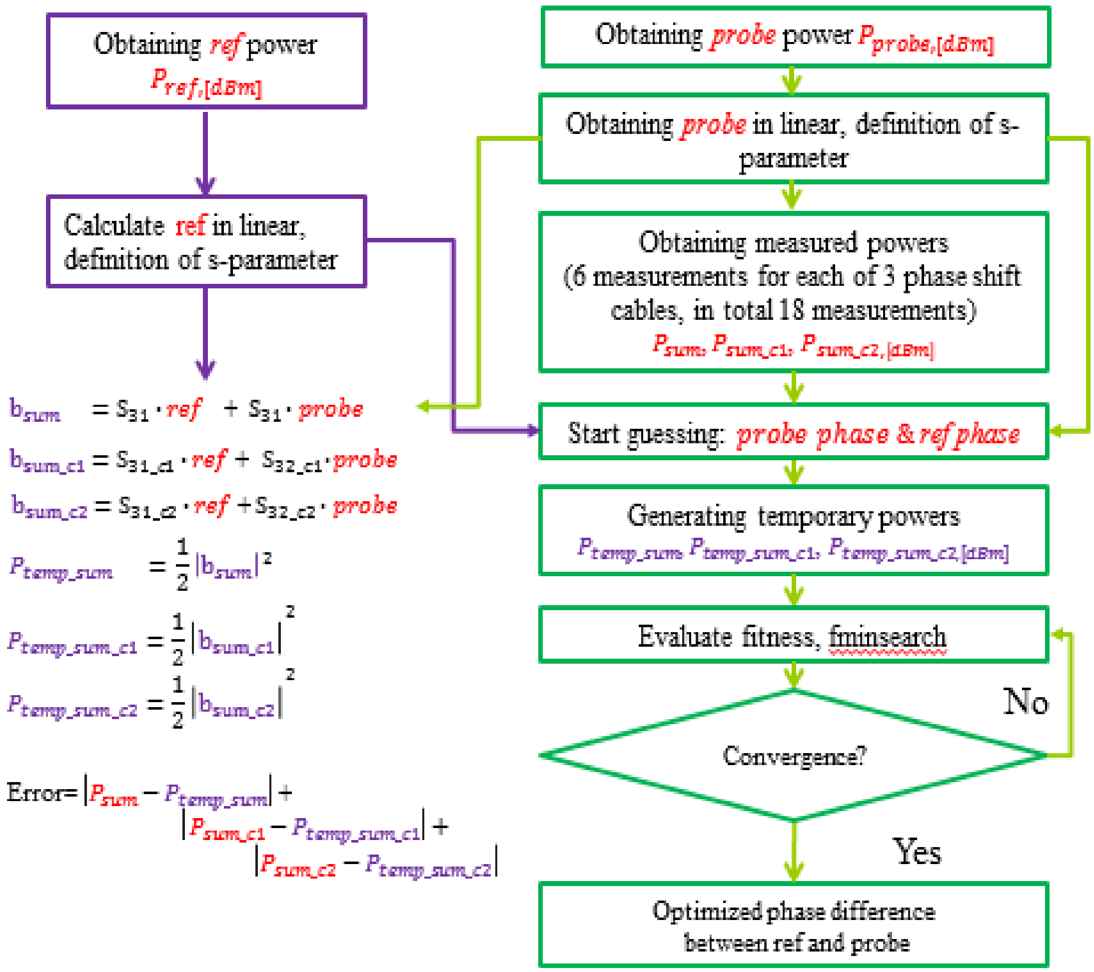

Figure 4.3. Measurement and post-processing algorithm.

The measured reference and main probe powers are in dBm units from the spectrum analyzer. They are converted to linear unit (voltage). These linear voltage values are then applied to the equations to calculate the terms b_{sum}, b_{sum_c1} and b_{sum_c2} for each phase shift cables. The measurement system has three phase shift cables labelled as ref, phase shift 1 and phase shift 2.

A total of six attenuation settings are used in this setup. This leads to a total of 6 measurements for each phase shift cable. There are a total of three phase shift cables into the reference path. Hence in total there are three mulitipied by six, eighteen measurements needed in this setup. It is important to understand that for a particular frequency of interest, the method needs only one attenuation value and three meausrements for different phase shift cables. This leads to a total of three meausrements required for each frequency. As a broadband frequency measurement solution, six different attenuation level settings are recorded. This is performed to enable detection of the phase of every freuqency within the broadband frequency set on the spectrum anlayzer. The power level of each frequency signal is not the same in real DUT, it may vary and have different signal strengths. This information is taken into account by having meausured the signal summations at for eighteen measurements.

The reference and main probe are given an initial guess phase value and the temporary powers P_{temp_sum}, $P_{temp\_sum\_c1}$ and $P_{temp\_sum\_c2}$ are generated. Using the temporary power values, fitness of the funciton is determined by calculating the error using the formula

$$\text{Error}= \left|P_{sum} - P_{temp\_sum}\right| + \left|P_{sum\_c1} - P_{temp\_sum\_c1}\right| + \left|P_{sum\_c2} - P_{temp\_sum\_c2}\right|$$

This fitness is determined using fminsearch and convergence criteria is determined by the fminsearch optimization algorithm. The algorithm is implemented in matlab software. Once the convergence criteria is met, the phase difference between the main probe signal and the reference signal is obtained.

4.2. VERIFICATION OF THE MODIFIED HYBRID COUPLER SETUP

The measurement setup is verified by the checking the system s-parameters based on calculated powers. The block diagram of the modified hybrid coupler setup is as shown in Figure 4.4.

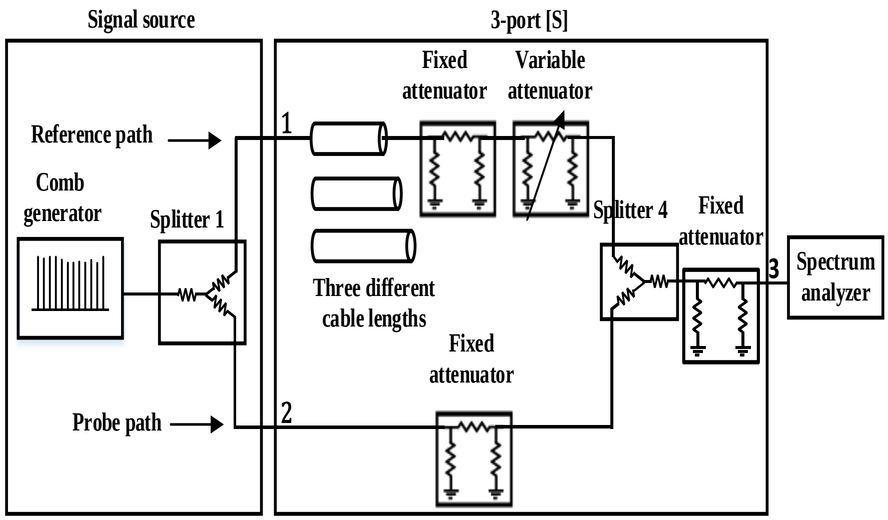

Figure 4.4. Block diagram of modified hybrid coupler setup.

The verification steps are as follows:

- The comb generator is used as a source to test the system. The splitter 1 splits the comb generator signal to create the test reference signal and the main probe signal. The two signals are directly measured using the spectrum analyzer.
- The signal power is known in to the reference path and the main probe path. Using the measured system s-parameters for the reference path (port 1 to port 3) and the probe path (port 2 to port 3) the expected or the calculated summation powers are generated for various attenuation levels.
- The comb generator signal after being split as reference and main probe signal are connected to the measurement system. The summation of the two signals from the reference path and the main probe path is measured using the spectrum analyzer.
- The two results are compared and plotted in the Figure 4.5. The phase difference between the reference and the main probe signals is 0° degrees.

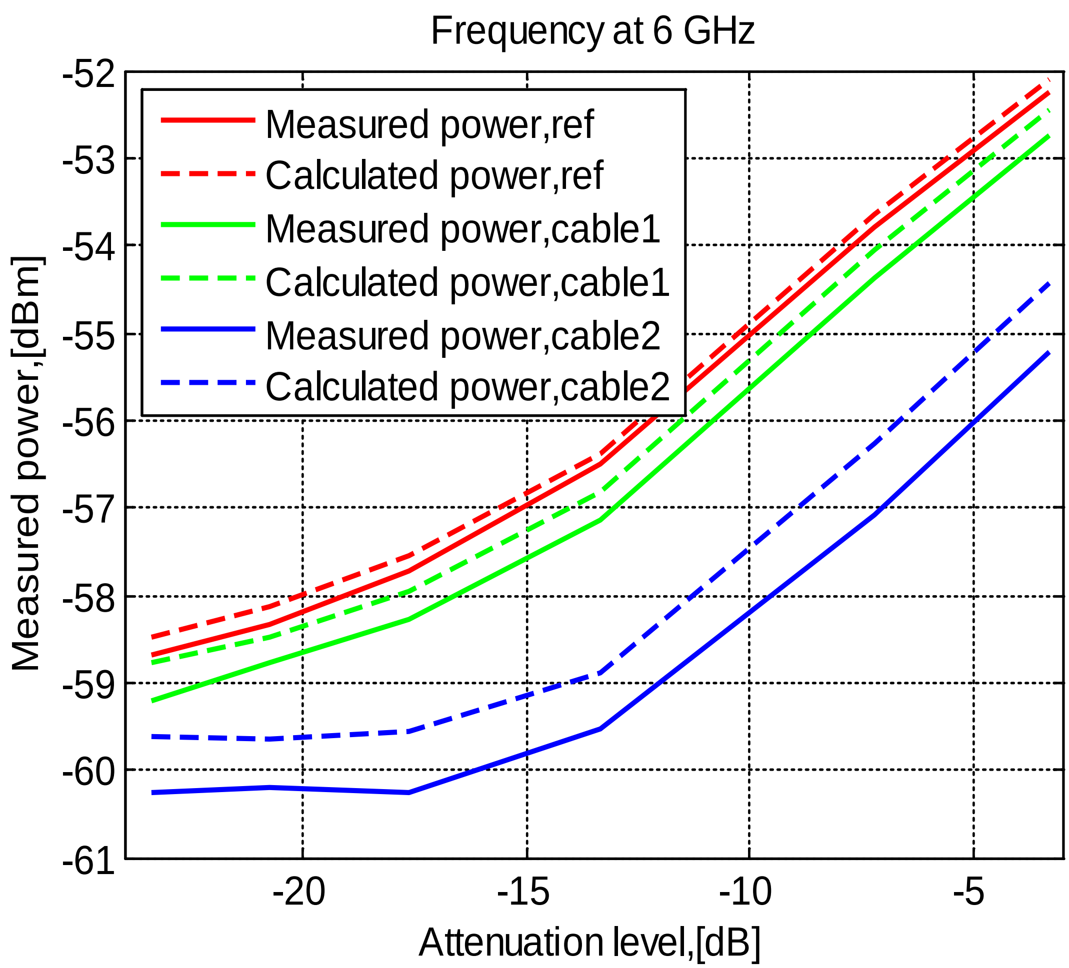

Figure 4.5. Verification of the measured and calculated power at the spectrum analyzer.

The calculated powers and measured powers for each of the three phase shift cables for the six different attenuation setting show a good match. The match is within 0.5 dB for a signal at 6 GHz.

In Figure 4.6 the source setting had an equal signal strength for both the reference and main probe signal. The attenuation control voltage of - 0.5 V to the attenuator has minimum power difference between the reference and the probe powers. The phase value corresponding to the attenuator control voltage is about 13° degrees. The phase difference between the two signals at the input is 0° degrees. The retrieved phase using this method is within $\pm$ 15° degrees of the expected phase value.

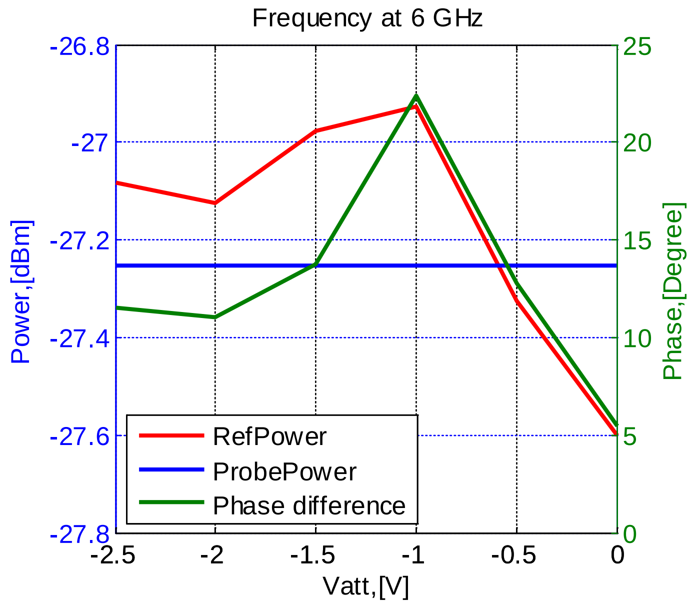

Figure 4.6. Verification of the retrieved power and phase difference.

The method is verified again by introducing a small cable to introduce a known phase shift at the source. The cable S_{21} is measured using VNA to determine the phase shift introduced. Similarly the steps are repeated to verify the measurement setup as shown in Figure 4.7.

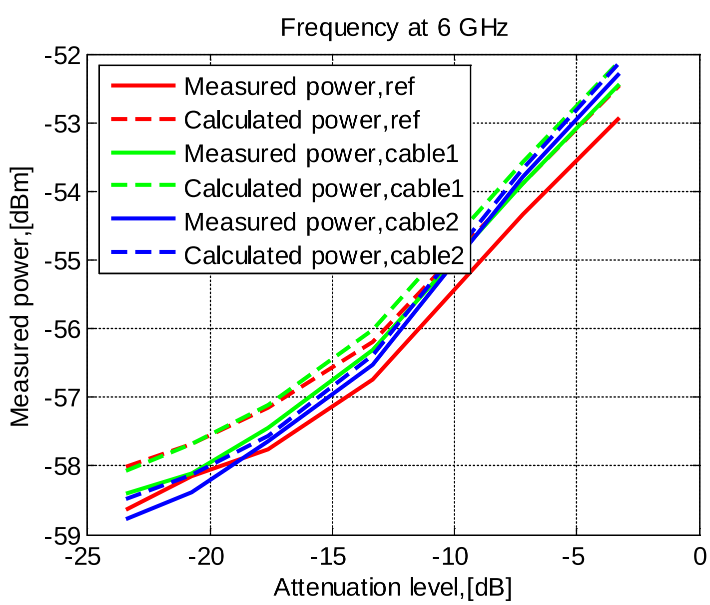

Figure 4.7. Verification of the measured and calculated power at the spectrum analyzer.

The retrieved power and the retrieved phase at 6 GHz are shown in Figure 4.8 and Figure 4.9 respectively.

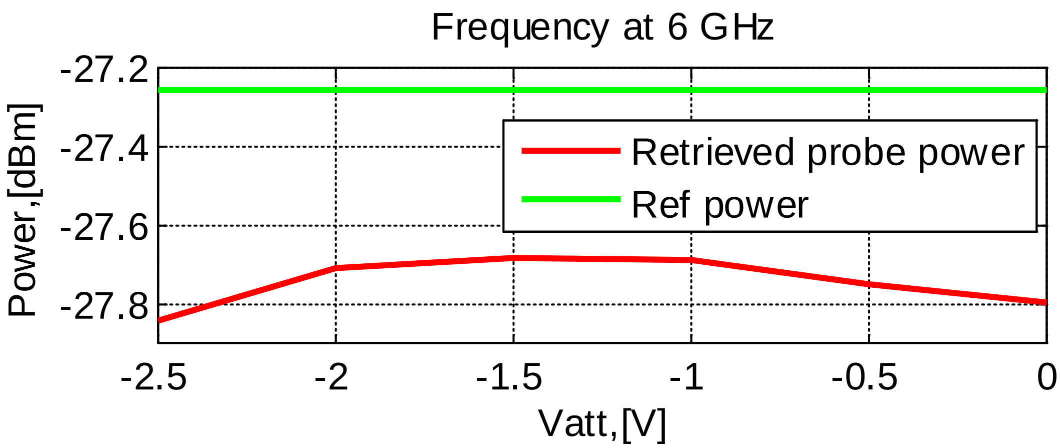

Figure 4.8. Verification of the retrieved power at 6 GHz.

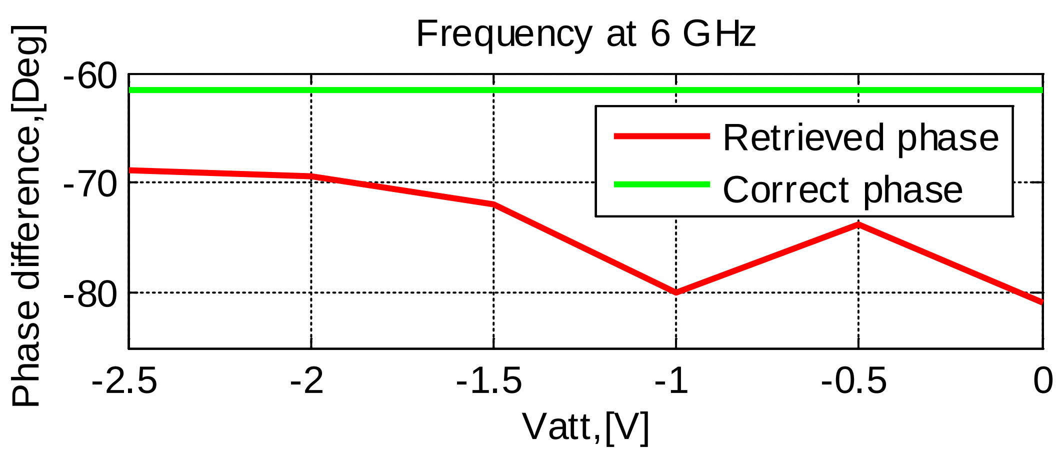

Figure 4.9. Verification of the retrieved phase at 6 GHz.

The attenuation control voltage of -1.5 V to the attenuator has minimum power difference between the reference and the probe powers. The phase value corresponding to the attenuator control voltage is about -72° degrees. The phase difference between the two signals at the input is -60° degrees. The retrieved phase using this method is within ± 15° degrees of the expected phase value. Similarly the measurement method was verified at various frequency points like 7, 8, 9, 10, 11 and 12 GHz.

4.3. AUTOMATED HYBRID COUPLER MEASUREMENT SETUP

The phase measurement for EMI scanning applications is performed using near field probes to measure the near field sources from the DUT. The existing setup involved human intervention to change the phase shift cables during the measurement. To automate this process switches were introduced to automate the phase shift cable switching. In order to implement the switches, a relay switch board was designed to supply power to the switches and select between the three phase shift cables. The automated measurement setup is shown in the Figure 4.10.

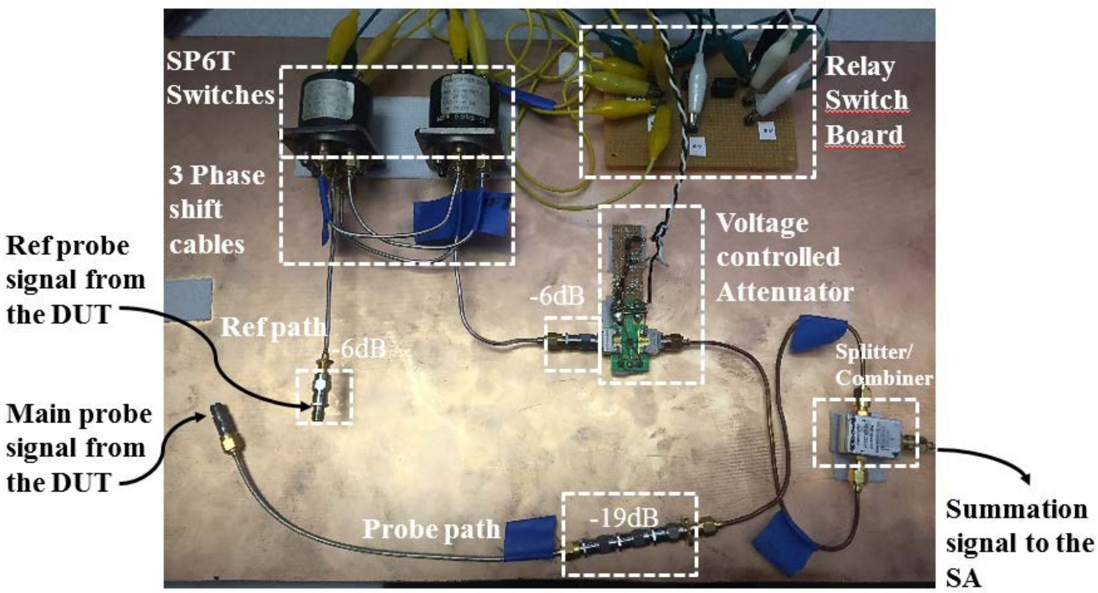

Figure 4.10. Automated phase measurement setup.

The components used in the system are mentioned in the below sections.

4.3.1. Switch. The switches require a 28 Vdc source. This is a single pole six throw RF coaxial switch. In this setup only three channels out of the six available channels are used. The connection is as follows:

- Channel 1 on both the SP6T switches is connected to the Ref cable.
- Channel 2 on both the SP6T switches is connected to the Phase shift cable1.

- Channel 3 on both the SP6T switches is connected to the Phase shift cable2.

NI USB 6341 DAQ is used to control the switching between the three channels of the SP6T channels. The voltage switching between channel 1, 2 and 3 is implemented by a using a relay switch board. The switches automate the phase shift cable switching process. The SP6T switches are shown in Figure 4.11.

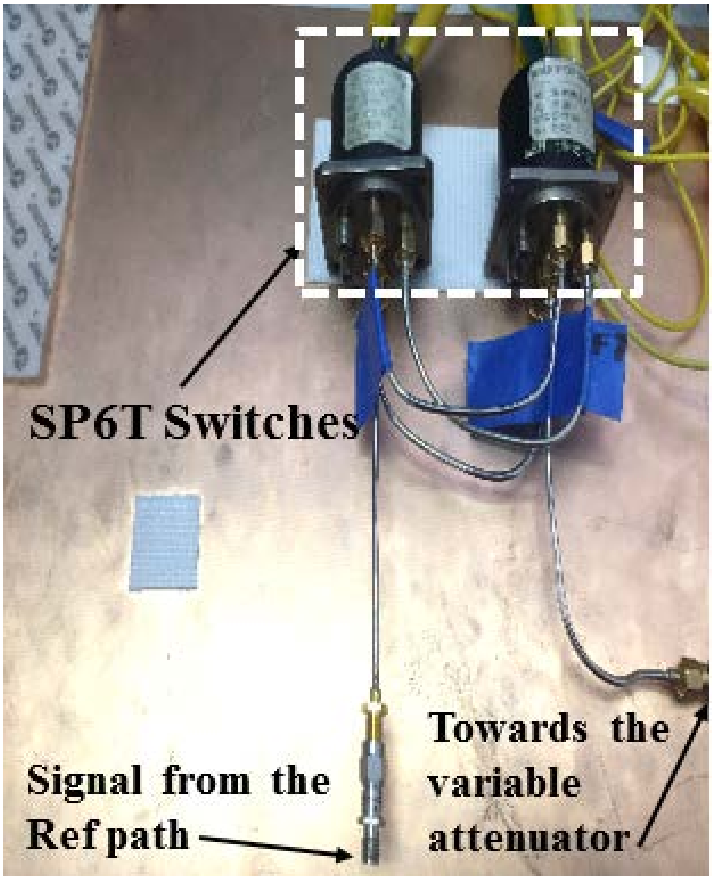

Figure 4.11. Dynatech FSCM SP6T switch.

4.3.2. Relay Switch Board. OMRON G5V-1 relays are used to switch in between the three channels on the SP6T switches. The two relays need 5 V control voltage to switch between the paths. The 5 V is supplied by the NI USB 6341 DAQ, which is controlled using an automation code in Matlab. The designed relay switch board is shown in the Figure 4.12.

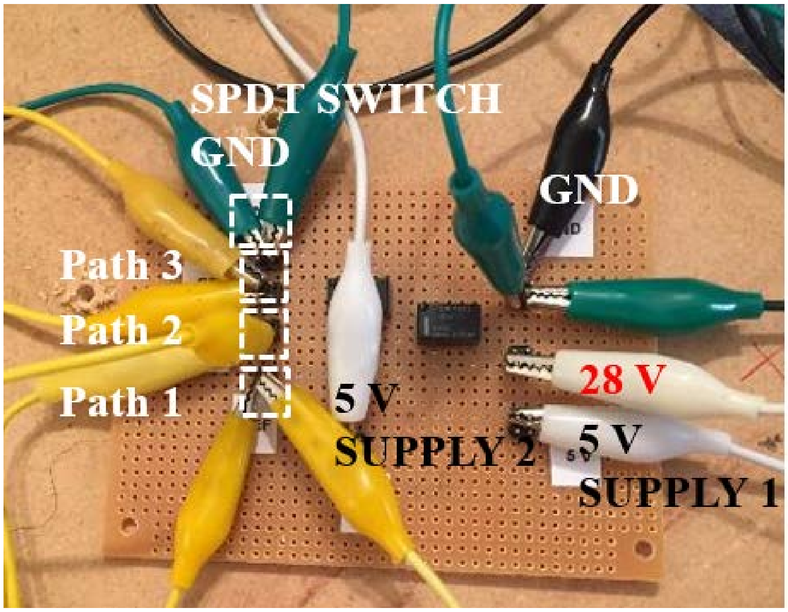

Figure 4.12. Relay switch board.

Based on the supply 1 and 2 voltages, the 28 Vdc is applied to the respective channel on the SP6T switch. The path 1 corresponds to the Ref cable, path 2 to the phase shift cable1 and the path 3 to the phase shift cable2. The supply voltage to path selection relationship is shown below in the Table 4.1.

Table 4.1. A truth table to explain the control voltages and the path selection relationship.

Path	Supply 1	Supply 2
Path 1	0 V	0 V
Path 2	5 V	0 V
Path 3	5 V	5 V

4.3.3. Voltage Controlled Attenuator. The HMC712LP3C from Analog devices is a wide band analog voltage controlled attenuator in the frequency range from 5 GHz to 26.5 GHz. It has an attenuation range of 28 dB. The analog control voltage range varies from 0 V to -3 V with 0 V corresponds to the maximum attenuation and -3 V corresponds to the least attenuation. A Zener diode based protection circuit is designed to protect the attenuator from reverse polarity voltage based damage. The diode circuit was implemented on a bread board and the ground of the bread board and the attenuator PCB were soldered together. The combined structure is shown in Figure 4.13.

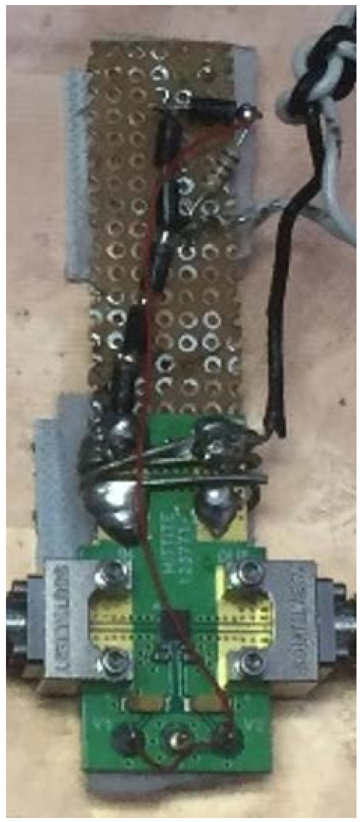

Figure 4.13. HMC712LP3C voltage controlled attenuator.

4.3.4. Splitter/ Combiner. The coaxial power splitter/ combiner is a 2 way resistive 50 Ω device. It frequency of operation is from DC to 12 GHz. The ZFRSC-123+ from mini-circuits is used to combine the powers from the two signal paths and send the summation signal to the spectrum analyzer. The port 1 corresponds to the main probe signal, the port 2 corresponds to the reference signal and the port S corresponds to the summation signal. The power splitter is shown in Figure 4.14.

Figure 4.14. ZFRSC-123+ power splitter from DC to 12 GHz.

5. NEAR FIELD SCAN RESULTS

The optimized phase measurement method is now compared with a resonant trace structure PCB (DUT) and its magnitude and phase results are compared to other measurement instrument methods like VNA and the Oscilloscope.

The highlighted area on the resonant trace structure PCB is the near-field scan area over which the magnitude and phase comparison is performed over different methods. The resonant trace structure PCB and the near field scan area is shown in Figure 5.1.

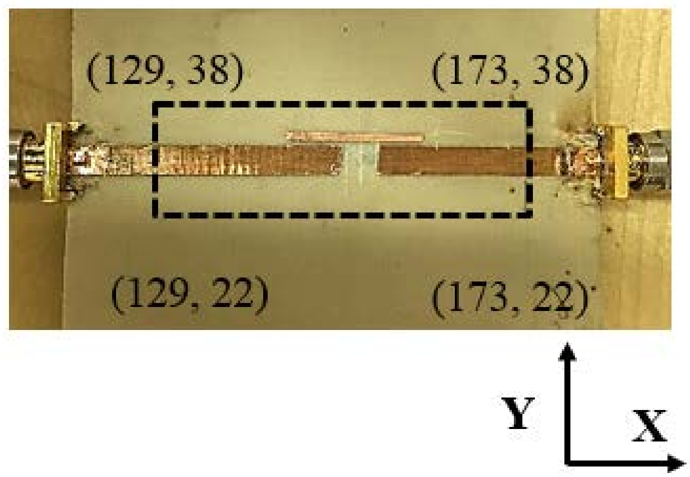

Figure 5.1. Resonant trace structure PCB for near field scanning.

A comb generator is used as a source excitation to generate the required near field radiation fields necessary for the near-field scanning.

EMI H_x probe was assembled to perform the measurements on the resonant trace structure as shown in Figure 5.2. To measure the field above the device under test with a higher spatial resolution, a H_x probe of loop size 2 x 2 mm is assembled. The probe is used to scan the H_y field above the PCB surface. The H_x probe is rotated by 90° to measure the H_y field over the DUT. The DUT is scanned at a spatial resolution of 2 mm. The width of the scan area is about 44 mm and the depth is about 16 mm.

Figure 5.2. Assembled EMI H_x probe with 2 mm x 2 mm loop size.

The fields are plotted over the scanned region. The magnitude and the phase are compared over the scanned area using the VNA, scope and spectrum analyzer instrument. The near field scan DUT setup is shown in Figure 5.3.

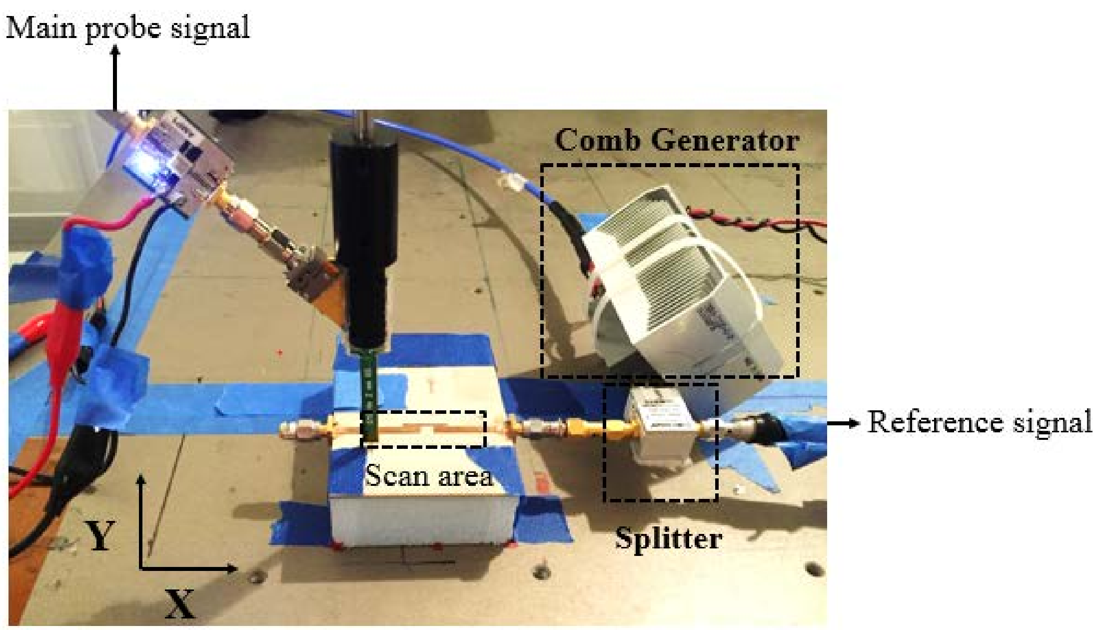

Figure 5.3. The trace resonant structure (DUT) is scanned using H-field probe.

The comb generator acts as a signal source. The comb generator requires a 200 MHz input signal source with an amplitude of 10 dBm. This input signal is generated using an Agilent signal generator. The comb generator generates an output signal from 200 MHz to 12 GHz at 200 MHz spacing. The comb generator output is connected to the ZFRSC-123+ power splitter. The power splitter splits the signal into two signals outputs. One output signal is fed to the resonant trace structure and the other output signal is used a reference signal. A constant RBW of 200 KHz was chosen to measure the DUT signals using the three instruments. The goal is to compare the phase values retrieved by the three instruments over the DUT.

5.1. VNA METHOD

The Vector Network Analyzer (VNA) instrument is used in Tuned receiver mode. Keysight PNA-X N5245A VNA was used for this measurement. The VNA based phase measurement block diagram is shown in Figure 5.4.

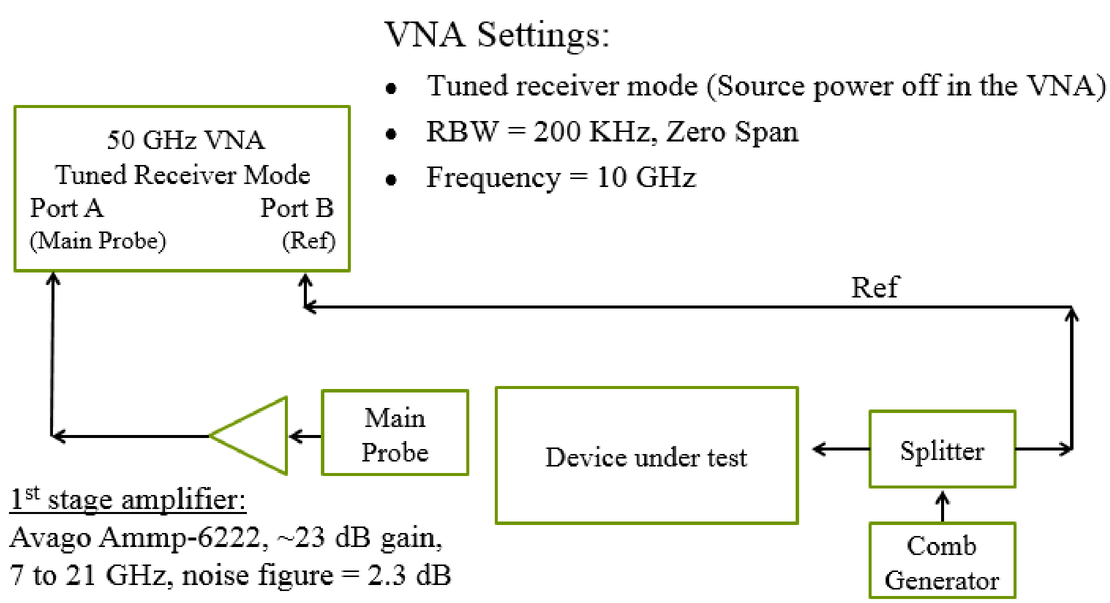

Figure 5.4. Block diagram for the VNA based phase measurement setup.

In the tuned receiver mode of the VNA, the internal source power is turned off. The main probe scanning signal is connected to the Port 1 (Receiver A) and the reference signal from the DUT is connected to the Port 2 (Receiver B). Amplifiers are used to improve the signal to noise ratio for the main probe signal. The VNA is set at zero-span at 10 GHz. The intended frequency of interest is at 10 GHz. The VNA resolution bandwidth is set at 200 KHz.

A Matlab based automation code is written to automate the scanning process. The H-field probe is mounted on the probe holder of a scanning robot. The Matlab automation code communicates between the VNA instrument and the scanning robot to perform the measurement over the DUT. The robot first moves to a point of the scan region and then the instrument captures the signals from the probe over the DUT. The probe signal is amplified using amplifiers and fed to the Receiver A. The reference signal is measured on the Receiver B channel of the VNA.

The magnitude of the main probe signal and the phase difference between the main probe signal and the DUT is plotted in Figure 5.5. Probe factor is applied to the measured signal at the VNA. Probe factor is the transformation applied to the signal detected by the SMA connector end of the probe and convert it to the field value measured at the probe loop.

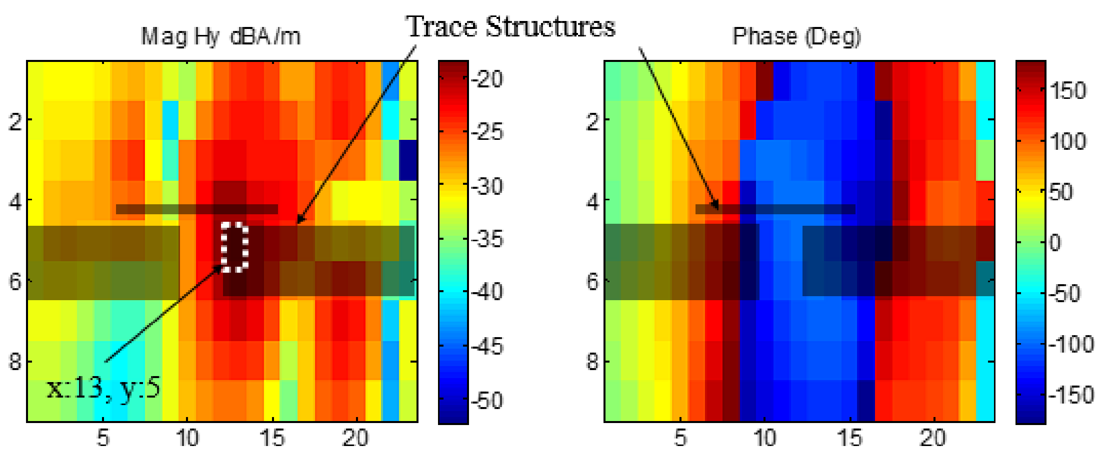

Figure 5.5. The magnitude of the main probe signal and the phase difference between the main probe signal and the reference signal in degrees over the scanned area using VNA.

The resonant trace structures are shown in black color boxes over the scanned data plots. The maximum point in the H-field is seen at the region where the thin trace is close to the edge of the right-section of the cut trace. The maximum H-field is observed at location (13, 5) with a magnitude of -18.47 dB A/m and phase about - 97° at 10 GHz.

5.2. SCOPE METHOD

The Keysight DSO9404A scope was used for this measurement. The frequency bandwidth of this scope is from DC to 4 GHz. The desired frequency of interest is 10 GHz. Hence a down mixing system is designed to down mix the RF signal of 10 GHz to a lower IF frequency which is within the bandwidth of the 4 GHz scope.

The down mixing was implemented using a system of external components like the high pass filter, the low pass filter and a down mixer. These external components we obtained from Mini-circuits. The block diagram of the down mixing for the main probe signal and the reference signal is shown in Figure 5.6.

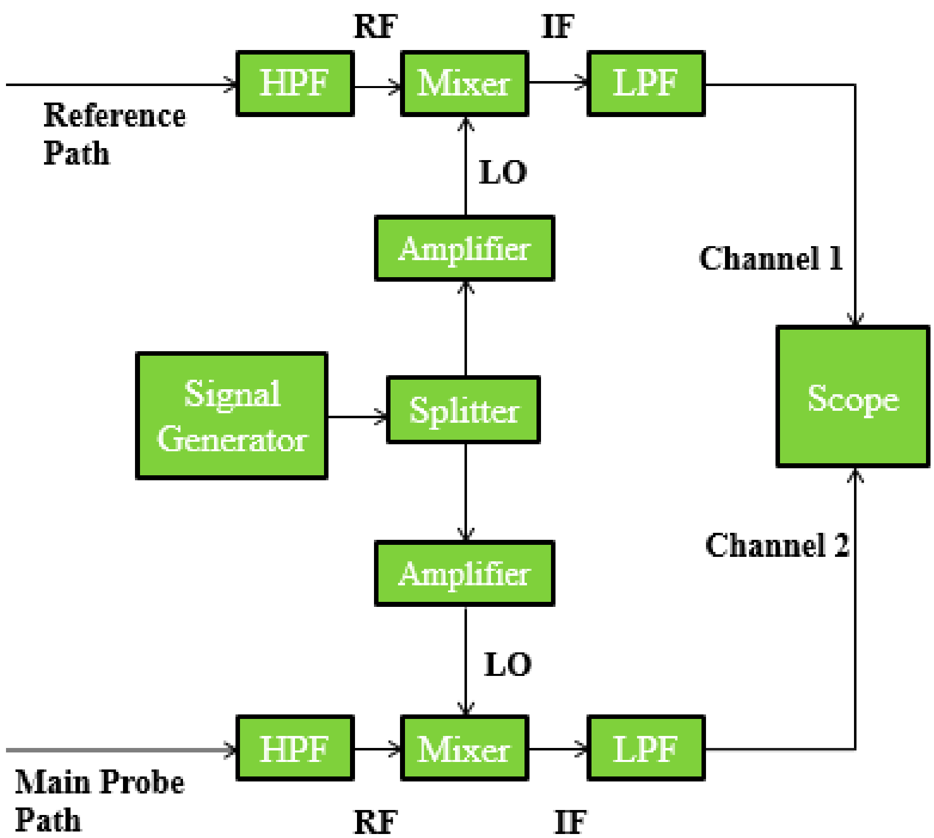

Figure 5.6. Block diagram of the frequency down mixing for the main probe and the reference signal.

The following components were used:

- HPF (VHF-6010+), Minicircuits, 6.3 GHZ -15 GHz
- Frequency mixer (ZX05-14+), Minicircuits, 3.7 GHz- 10 GHz
- LPF (VLF-3800+), Minicircuits, DC – 3.9 GHz

The RF signal in the range of 7 GHz to 10 GHz can be easily down mixed to an IF frequency range of less than 4 GHz. The local oscillator signal for the down mixing is generated using a 20 GHz VNA as a signal generator. The VNA sweep time is set to a maximum value of about 24 hours and the VNA is set to zero span at 9.87 GHz (local oscillator frequency). The VNA signal is split using a power splitter to generate a local oscillator signal for each of the down mixers, one for the main probe down mixing stage and the other for the reference signal down mixing stage. Since the power splitter introduces about 9 dB loss in the signal power level, amplifiers are used to boost the power level of the signal to +7 dBm. This requirement of +7 dBm is required by the mixer component ZX05-14+ from mini-circuits. The 20 GHz VNA output power is set at around 8.5 dBm. The high pass filter and the low pass filters are introduced in the mixing unit to remove any unwanted images frequencies from the mixer output signal. This stage is necessary to help capture the 10 GHz signal on a 4 GHz scope. The block diagram of the scope based phase measurement setup and the measurement setup is shown in Figure 5.7.

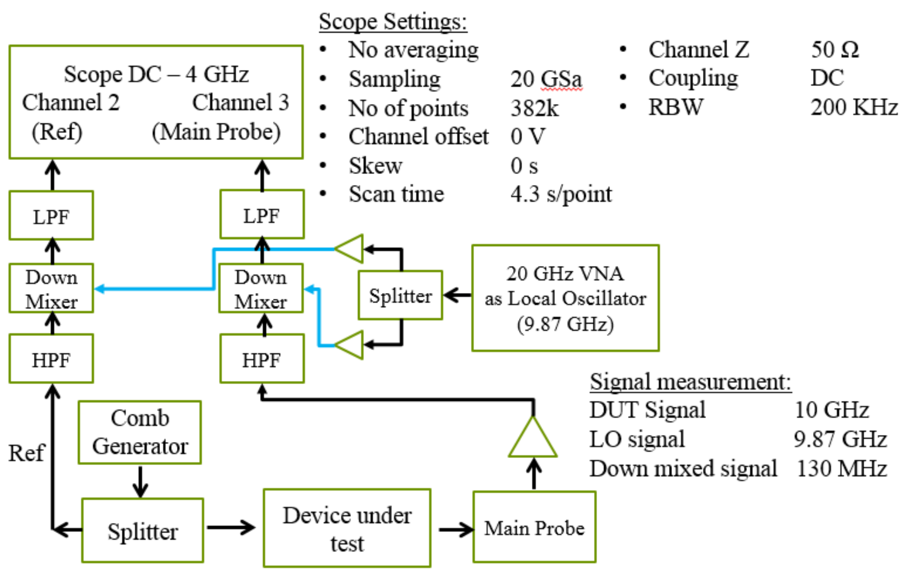

Figure 5.7. Block diagram of the scope based phase measurement setup.

The down mixing unit is shown in Figure 5.8 and Figure 5.9 respectively.

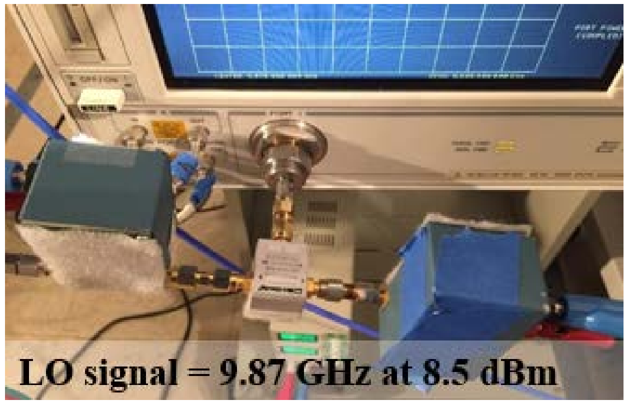

Figure 5.8. 20 GHz VNA signal output connected the splitter and the amplifiers. The output of the amplifiers is connected to the local oscillator port on the mixer.

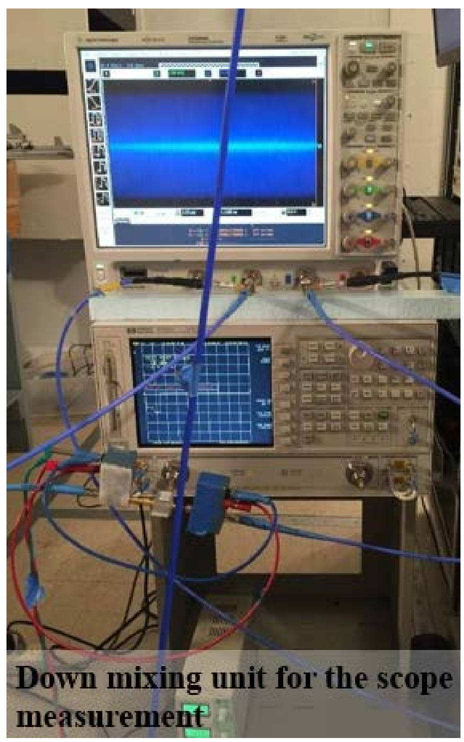

Figure 5.9. Entire down mixing unit and the measurement instrument scope is shown.

The RF signal of 10 GHz is down-mixed to 130 MHz using the down mixer. The channel is set to 50 Ω impedance for the main probe signal and the reference signal. The two signals are recorded in time domain and the recorded data is later postprocessed in Matlab code to perform FFT over the two signals and then determine the phase difference between the main probe signal and the reference signal.

A Matlab based automation code is written to automate the scanning process. The H-field probe is mounted on the probe holder of a scanning robot. The Matlab automation code communicates between the scope instrument and the scanning robot to perform the measurement over the DUT. The robot first moves to a point of the scan region and then the instrument captures the signals from the probe over the DUT.

The scope down mixing based magnitude of the main probe signal and the phase difference between the main probe signal and the DUT is plotted in Figure 5.10. Probe factor is applied to the measured signal at the scope. The time domain data is converted to frequency domain data using FFT in the Matlab based post-processing and then the probe factor correction is applied to obtain the signal in dB A/m units.

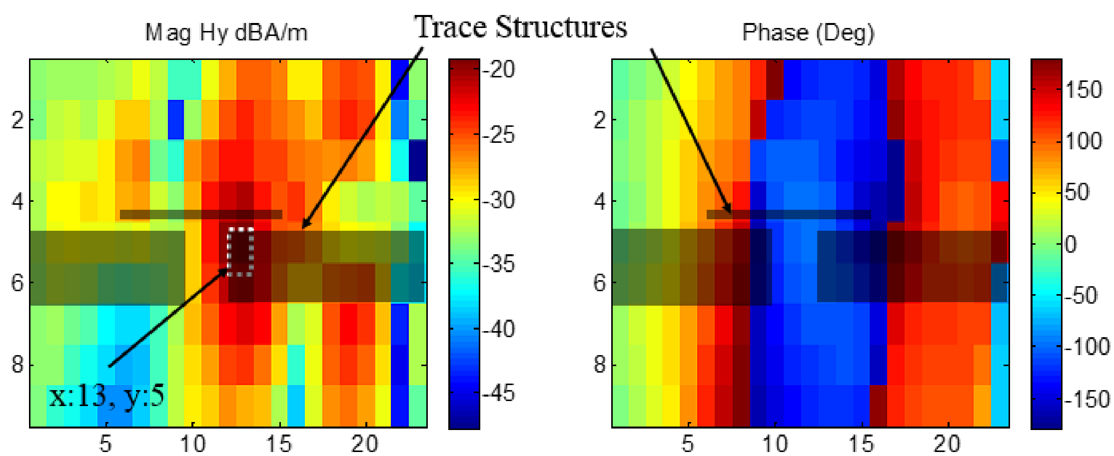

Figure 5.10. The magnitude of the main probe signal and the phase difference between the main probe signal and the reference signal in degrees over the scanned area using scope.

The resonant trace structures are shown in black color boxes over the scanned data plots. The maximum point in the H-field is seen at the region where the thin trace is close to the edge of the right-section of the cut trace. The maximum H-field is observed at location (13, 5) with a magnitude of -19.1 dB A/m and phase about - 102° at 10 GHz.

5.3. SPECTRUM ANALYZER METHOD

The spectrum analyzer instrument was setup to measure in a frequency bandwidth from 9 GHz to 10.2 GHz at a 200 KHz resolution bandwidth for this measurement. It should be noted that the spectrum analyzer based method is wideband method and its frequency wideband limitation is based on the individual external component's frequency range like the voltage controlled attenuator, power splitters, phase shift cables, SP6T switches and the fixed attenuators used in building the measurement setup.

In the current state of the art of the measurement system, the frequency range is from 5 GHz to 12 GHz. The automated hybrid coupler based method is shown in the Figure 5.11.

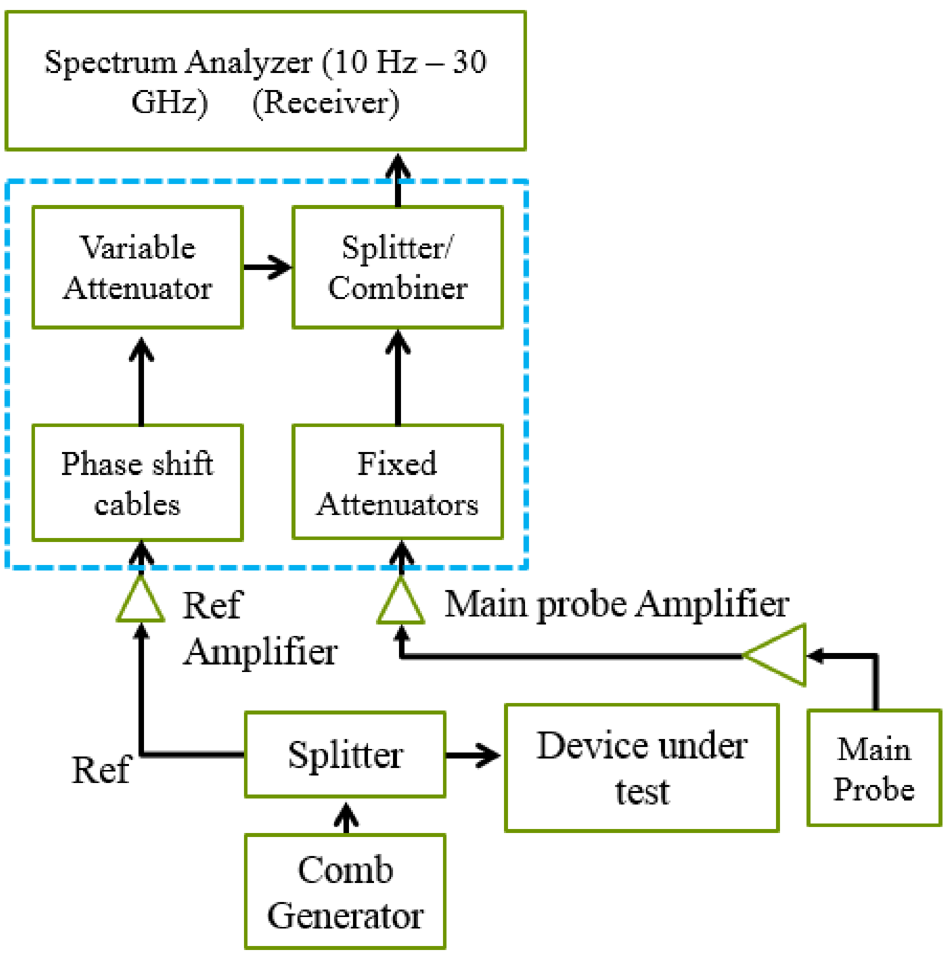

Figure 5.11. Block diagram of the spectrum analyzer method.

The scanning steps used during the automated measurement are listed in the Figure 5.12.

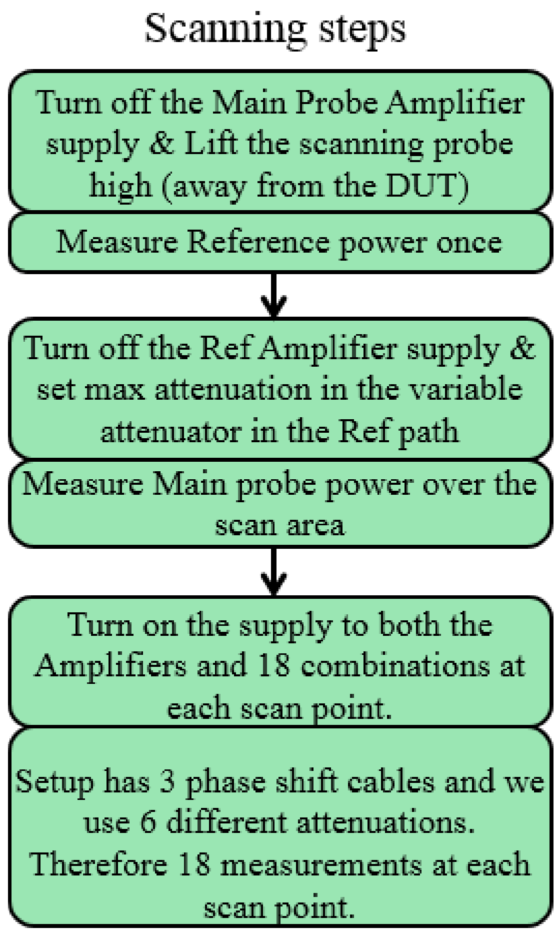

Figure 5.12. The scanning steps involved in the automated spectrum analyzer based phase measurement method.

A Matlab based automation code is written to automate the scanning process. The H-field probe is mounted on the probe holder of a scanning robot. The Matlab automation code communicates between the spectrum analyzer instrument and the scanning robot to perform the measurement over the DUT. The robot first moves to a point of the scan region and then the instrument captures the signals from the probe over the DUT. The scanning steps mentioned in Figure 5.12 are included within the Matlab automation code.

The magnitude of the main probe signal and the phase difference between the main probe signal and the DUT is plotted in Figure 5.13. Probe factor is applied to the measured signal at the spectrum analyzer.

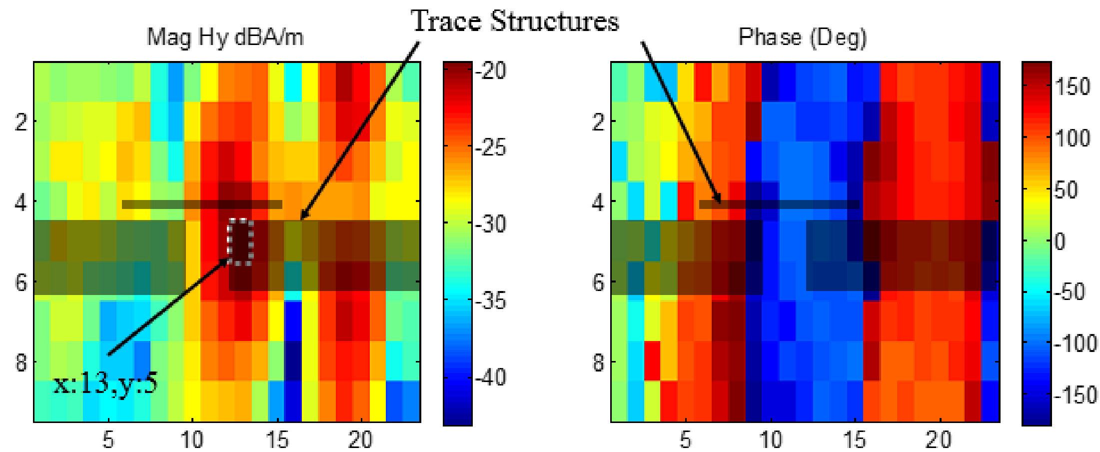

Figure 5.13. The magnitude of the main probe signal and the phase difference between the main probe signal and the reference signal in degrees over the scanned area using a spectrum analyzer.

The resonant trace structures are shown in black color boxes over the scanned data plots. The maximum point in the H-field is seen at the region where the thin trace is close to the edge of the right-section of the cut trace. The maximum H-field is observed at location (13, 5) with a magnitude of -19.5 dB A/m and phase about –98.45° at 10 GHz.

5.4. COMPARISON OF THE MEASUREMENT METHODS

The near field scanned data over the resonant trace structure at 10 GHz is compared for the magnitude and phase results using the three methods. The VNA and scope methods are existing methods in the literature and the spectrum analyzer method is compared to these measurement methods. The VNA and scope magnitude comparison is shown in Figure 5.14.

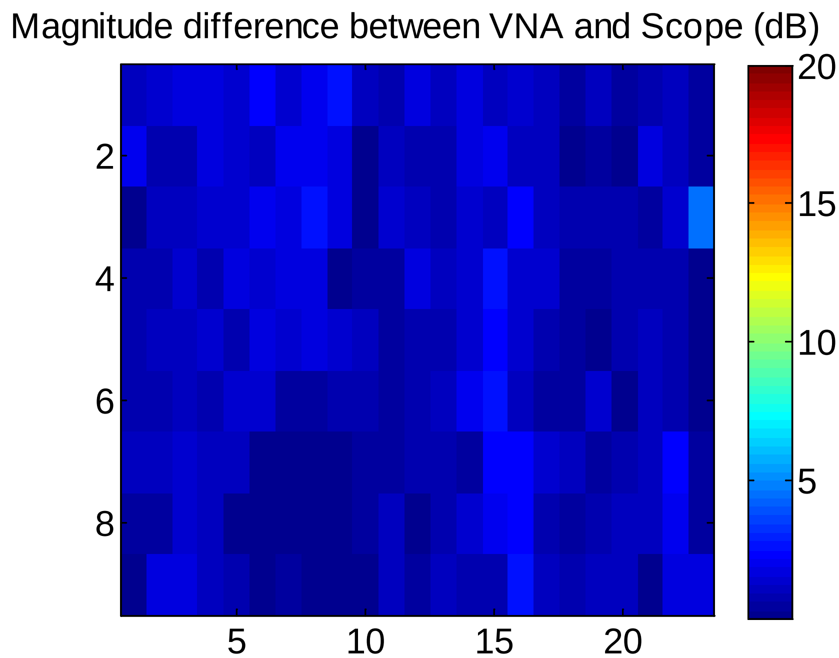

Figure 5.14. Comparison of the VNA and Scope based magnitude measurement.

The VNA and spectrum analyzer based magnitude comparison is shown in Figure 5.15.

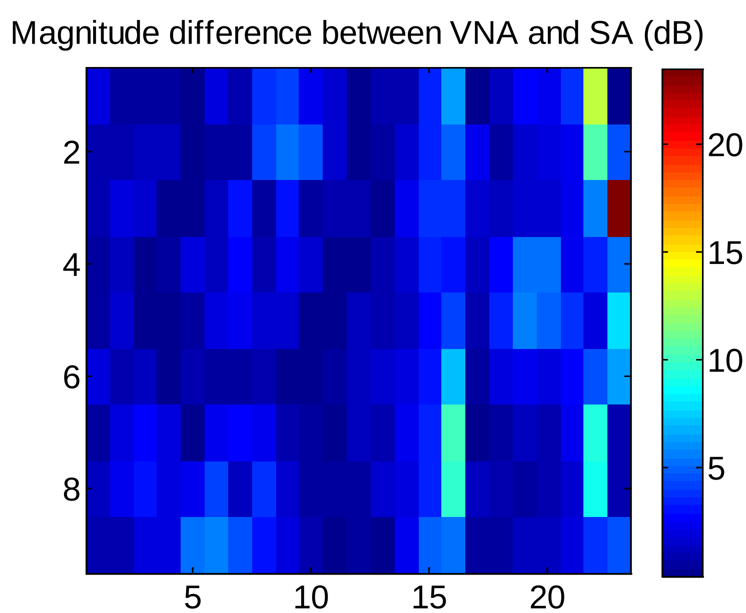

Figure 5.15. Comparison of the VNA and spectrum analyzer based magnitude measurement.

The comparison plots show that the measurement difference in dB for each scan point over the scanned area above the resonant trace structure. The plots show that the magnitude of the scanned area is within 5 dB of measured power using the VNA measurement as a reference. Similarly the analysis is performed for the retrieved phase results. The VNA and scope phase comparison is shown in Figure 5.16.

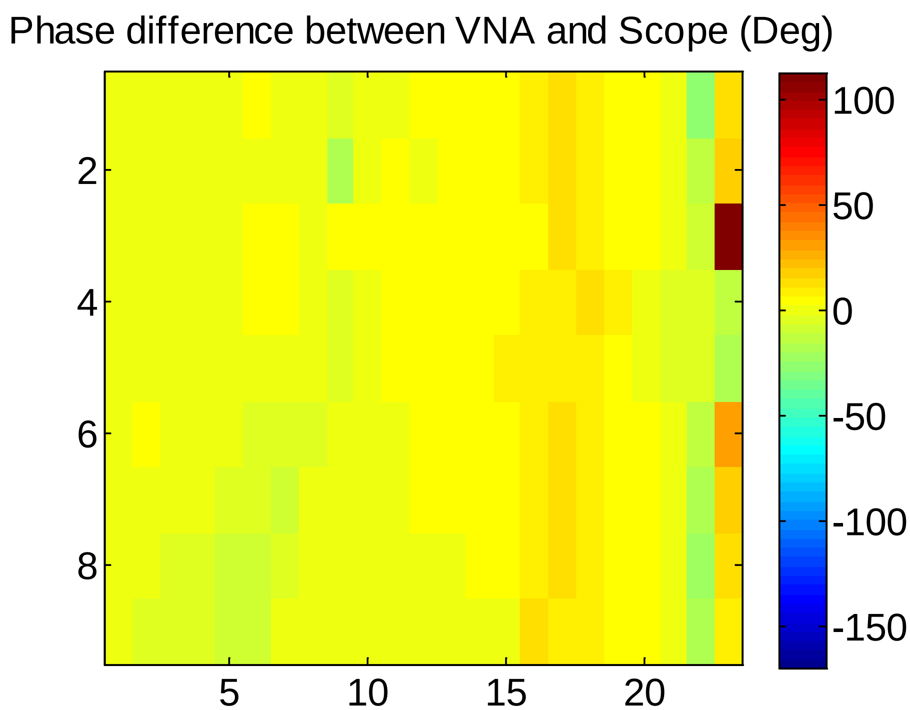

Figure 5.16. Comparison of the VNA and Scope based phase measurement.

The VNA and spectrum analyzer based magnitude comparison is shown in Figure 5.17. The VNA and scope method's phase retrieved values are within ± 20° of difference for most of the scan points. The SA phase scan data predicts similar trends but the phase variation at few scan points is more than ± 20° when compared to VNA phase retrieval. The phase variation observed in the comparison plots for the spectrum analyzer method may be due to the magnitude difference between the individual measurements at a particular scan point. This may happen if the source has amplitude variation.

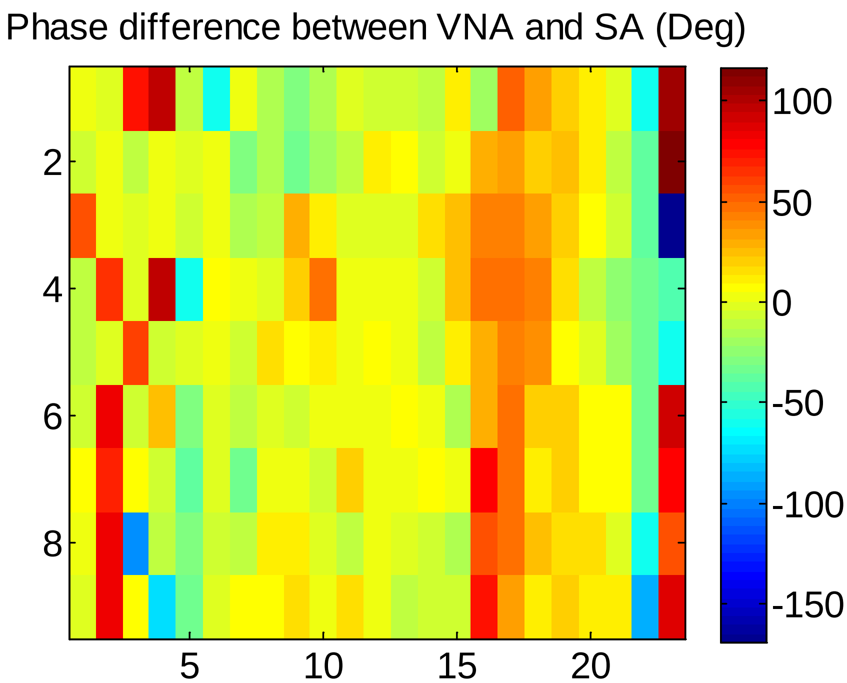

Figure 5.17. Comparison of the VNA and spectrum analyzer based phase measurement.

Another source of error can be the optimization function fminsearch, if it does not converge completely to the criteria set by the user. These are few of the reasons which affect the phase retrieval by the spectrum analyzer based phase measurement method.

6. CONCLUSIONS AND FUTURE WORK

6.1. CONCLUSIONS

- Retrieved phase is dependent and highly sensitive to the signal to noise ratio of the signal being measured.
- The designed external components measurement setup requires about 18 frequency span measurements for a broadband measurement and have a dynamic range of about 30 dB using a spectrum analyzer.
- The sweep time to perform a broadband frequency measurement on a spectrum analyzer is dependent on the spectrum analyzer instrument settings like the resolution bandwidth, frequency range and the number of points.
- The instrument can be programmed to measure only specific frequency points of interest, but using this method does not improve the scanning time. The scanning time is a function of the instrument sweep time and remote control automation command communication using GPIB/ LAN interface. This was observed to the specific R&S FSV 30 GHz signal analyzer. Using different vendor’s spectrum analyzers may results in a slight different performance based on the instrument communication and the instrument settings.
- The frequency range of the proposed setup is from 5 GHz to 12 GHz. The effective frequency range of the method is determined by the phase shift cables, switches, attenuators and the combiner components individual frequency range. The frequency range of the phase measurement method is set up the individual frequency range of the external components used in building the phase measurement setup.
- The measurement method for the near field EMI scanning application is demonstrated.

6.2. FUTURE WORK

- To build a product based system and implement this method as an add-on option (functionality) to the market available Spectrum Analyzer instrument.

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VITA

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